

The Financial Impact of Schedule Delays on The Kucing Liar (KL) Project at PT Freeport Indonesia: A Scenario-Based Discounted Cash Flow Analysis

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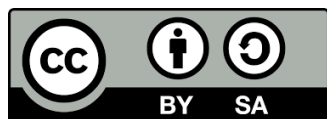
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Abstract

PT Freeport Indonesia (PTFI) is transitioning from the depleted Grasberg open-pit mine to underground block-caving operations, with Kucing Liar (KL) representing its largest underground mining project. Production is scheduled to commence on July 1, 2029, while the current mining license expires in 2041. Given this fixed expiration date, schedule delays could defer revenue generation and reduce project value, highlighting the need for a quantitative assessment of delay-related financial losses and schedule-protection investments. This study developed a deterministic discounted cash flow (DCF) model using the 3Q26R2 mine plan, the 2023 feasibility study, and company cost data covering 2021–2041, expressed in constant 2026 U.S. dollars. The analysis incorporated three scheduling scenarios, six cost-escalation variants, and sensitivity assessments. The base-case net present value (NPV) was \$9,408 million at a 10% real discount rate, with a projected payback period ending in 2032. A six-month delay reduced NPV by \$665 million, while a 12-month delay combined with a 10% cost escalation resulted in a \$1,569 million reduction (16.7%). The estimated financial impact averaged \$111 million per month of delay, increasing to \$138 million when capital expenditures could not be rescheduled. Approximately two-thirds of the NPV reduction resulted from deferred cash flows, while the remaining loss was attributable to production extending beyond the 2041 license expiration. Across cost-escalation scenarios, the financial impact ranged from \$110 million to \$119 million per month, with schedule performance demonstrating approximately three times greater influence on project value than development capital expenditures. The findings established an economic basis for schedule-protection investments, including buffer ore stockpiles, milestone-based contractor incentives, and conditional contingency reserves, with benefit-cost ratios ranging from 1.9 to 4.9. A five-year mining license extension was estimated to generate an additional \$1,981 million in project value. Furthermore, monthly monitoring of development tonnage could identify potential schedule deviations as early as April 2027, rather than 2031, enabling earlier corrective interventions.



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INTRODUCTION

Mining projects require substantial capital investment and typically involve extended payback periods, as demonstrated by the operations of PT Freeport Indonesia (PTFI). Following the depletion of reserves in the Grasberg open-pit mine, PTFI transitioned to underground mining using the block-caving method, with the Kucing Liar (KL) project emerging as its largest new underground development. This study

addresses a central research question: What is the financial impact of schedule delays on the KL project? To answer this question, schedule delays were incorporated as input variables into a discounted cash flow (DCF) model (Breay Myers Allen, 2003). The technical causes of delays were excluded from the scope of the study, allowing the analysis to focus specifically on their financial consequences. By relying on available operational and financial data, the study aimed to provide findings that are accessible and relevant to both technical and financial decision-makers (Samis et al., 2005; LaRoche-Boisvert et al., 2021; Furtado e Faria et al., 2022).

PTFI operates the Grasberg mining complex in Papua, Indonesia. Following the closure of the open-pit mine, mining operations transitioned to underground deposits, including Big Gossan, Grasberg Block Cave (GBC), and the Deep Mill Level Zone (DMLZ), while KL became a major ongoing development project (Yang et al., 2022). The 2023 Feasibility Study reported ore reserves of 381 million metric tons (Mt), with average grades of 0.99% copper and 0.88 grams per metric ton (g/t) of gold, representing sufficient resources to support mining operations for at least 20 years beyond the current license term (PTFI, 2023). Under the existing mine plan, development ore production is scheduled to begin in 2027, followed by the commencement of cave production on July 1, 2029 (Khan & Asad, 2021; Sotoudeh et al., 2020). Production is projected to increase progressively to 130,000 metric tons per day by 2035, with cumulative production estimated at 469 Mt by 2041. Development capital expenditures are projected to total US\$5,300 million during 2021–2033, of which US\$1,139 million had been incurred by the end of 2025. Sustaining capital expenditures are estimated at an additional US\$1,383 million during 2034–2041, while total operating expenditures for 2026–2041 are projected at US\$4,760 million, equivalent to approximately US\$10.15 per metric ton of ore (Alipour et al., 2022).

Large-scale mining developments frequently experience schedule delays and cost overruns. (Flyvbjerg, 2014) reported that approximately nine out of ten megaprojects experienced cost overruns, with schedule delays representing another recurring challenge. Similarly, (Vallée, 2000) identified persistent production shortfalls during the startup phases of mineral projects, often associated with insufficient geological characterization, metallurgical assessment, and feasibility evaluation. Moreover, future global copper supply increasingly depends on the development of large, deep, capital-intensive mineral deposits comparable to KL (Mudd & Jowitt, 2018). Schedule delays at KL may generate two distinct financial consequences. The first arises from the time value of money, whereby deferred cash flows have a lower present value. The second results from the limited mining license term. Because PTFI's Special Mining Business License for Production Operations (Izin Usaha Pertambangan Khusus Operasi Produksi, IUPK-OP) is scheduled to expire in 2041, delayed production extending beyond this period cannot be recovered under the existing license assumptions. A DCF model provides a systematic framework for quantifying both financial effects without requiring detailed engineering simulations.

PTFI's ownership structure comprises a 48.76% interest held by Freeport-McMoRan Inc. and a 51.24% interest held by Indonesian government-controlled entities through PT Indonesia Asahan Aluminium (Inalum) and Mining Industry Indonesia (MIND ID). The company operates copper and gold mining activities within the Grasberg mineral district under an IUPK-OP scheduled to expire in 2041, subject to potential extension with government approval. Ore extracted from underground mines is processed at the Mile Post 74 concentrator complex, which has an approximate processing capacity of 240,000 metric tons per day. The resulting concentrate is transported through a 118-kilometer slurry pipeline to the Amamapare port facilities (PTFI, 2023). The KL project is strategically important to this integrated production system because output from existing underground mines is expected to decline during the 2030s. According to the 3Q26R2 mill plan, KL is projected to contribute approximately 55% of the district's total mill feed by 2035 and 56% by 2041. Consequently, delays in KL production could create substantial feedstock shortfalls at the concentrator, extending the project's financial implications beyond its individual operating boundaries to the broader Grasberg mining complex.

PTFI has allocated approximately US\$5,300 million in development capital to KL based on the planned production schedule, making project value highly dependent on timely execution. The 2023 Feasibility Study identified several potential sources of schedule disruption, including challenging ground conditions, substantial groundwater inflows, and dependencies on other processing infrastructure projects. However, the study did not quantify the financial consequences of these risks (PTFI, 2023). Although potential schedule disruptions have been identified, the absence of a standardized monetary estimate for each month of delay limits the ability to evaluate schedule-protection investments objectively (Nelis et al., 2023). Project schedules are generally monitored in temporal units, whereas investment decisions are evaluated in monetary terms. This disconnect complicates assessments of mitigation measures, including performance-based contractor incentives, buffer ore stockpiles, contingency reserves, and additional development crews (Mangaonkar, 2024). Without an explicit financial valuation of schedule delays, such expenditures may be assessed primarily through managerial judgment rather than quantitative cost-benefit analysis. This challenge is particularly significant during the production ramp-up period leading to 2035, when delays could reduce recoverable production within the fixed license period ending in 2041.

Eight stakeholder groups were identified as having interests in the KL development schedule, although their influence over project execution and exposure to financial consequences varied considerably. PTFI management and development contractors exercised substantial influence over project delivery, while other stakeholders bearing financial exposure had comparatively limited control over scheduling decisions. Furthermore, the government authority responsible for mining licenses held a distinct regulatory role because an approved license extension could potentially mitigate production losses associated with the existing 2041 expiration date.

These differences highlighted a fundamental decision-making challenge: the absence of a quantified financial measure linking schedule performance to project value. Accordingly, the primary research problem was not simply the possibility of project delays but the lack of a reliable monetary estimate of their consequences. Addressing this gap required determining the reduction in project value associated with each month of schedule slippage (Lilford et al., 2018).

This study addressed five research questions. First, what were the projected base-case net present value (NPV) and payback period of the KL project under the company's existing production and cost assumptions? Second, how would schedule delays of six and twelve months, as well as a three-month schedule acceleration, affect project value? Third, how sensitive were these financial impacts to inflation assumptions and real changes in metal prices and operating costs throughout the modeled period? Fourth, which operational and financial variables exerted the greatest influence on KL's economic value, and how did schedule performance compare with other value drivers? Fifth, what level of expenditure on schedule-protection measures could be economically justified based on the estimated financial consequences of delays?

The corresponding research objectives were to develop a transparent base-case DCF model using company operational and financial data; quantify the effects of alternative scheduling scenarios on NPV, cash flows, and the payback period; evaluate the sensitivity of delay-related financial losses to cost-escalation assumptions; identify and rank the principal determinants of project value through sensitivity analysis; and establish an economically justified investment framework for evaluating schedule-protection measures. Collectively, these objectives were intended to translate schedule performance into measurable financial consequences and support evidence-based capital allocation decisions.

The analysis covered projected KL cash flows from 2026 through the expiration of the existing IUPK-OP in 2041. Ore production volumes and grades were obtained from the 3Q26R2 mine and mill plans, while development capital expenditures, sustaining capital expenditures, and operating costs were derived from the company's annual planning data covering 2021–2041. Metallurgical recovery rates and payable metal assumptions were obtained from the 2023 Feasibility Study and associated mill planning documents. Metal prices, fiscal parameters, and the discount rate were incorporated as explicit modeling assumptions and could be modified in the accompanying financial workbooks to evaluate alternative economic conditions.

Four limitations were recognized. First, schedule delays were treated as exogenous input variables, allowing the study to quantify the financial consequences of predetermined delay periods without estimating their probability or investigating their underlying technical causes. Second, the US\$1,139 million invested before 2026 was classified as a sunk cost and excluded from incremental NPV and payback calculations, consistent with established capital budgeting principles (Brealey et al., 2020). However, eligible historical capital expenditures remained within the applicable tax depreciation

base. Third, the model assumed that the existing processing infrastructure could accommodate all KL ore delivered under the evaluated production scenarios, thereby isolating the financial effects of ore-supply delays from potential processing-capacity constraints. This assumption was consistent with the 3Q26R2 production scenario, which maintained an approximate total processing capacity of 240,000 metric tons per day, including KL ore. Fourth, the base-case valuation was restricted to the existing mining license period ending in 2041. A potential license extension was not incorporated into the base-case assumptions but was evaluated separately to estimate its additional economic value (Haque et al., 2014; Espinoza & Rojo, 2017; Shafiee & Topal, 2010).

METHOD

Research Design and Data

(Savolainen, 2016; Lilford, 2023) This study employed a quantitative, model-based approach using a deterministic discounted cash flow (DCF) model to ensure the traceability and reproducibility of results. The research was conducted in five phases, with the primary analyses focusing on base-case valuation (Phase 3), financial risk assessment (Phase 4), and cost-benefit evaluation of mitigation strategies (Phase 5). All calculations were performed using interconnected formulas across six Excel workbooks, allowing alternative assumptions and scenarios to be evaluated. The model quantified the financial consequences of specified schedule delays without estimating their probabilities. The analysis relied exclusively on secondary company data, without primary data collection or interviews (Table 1).

Table 1. Data Collection Matrix

Data Category	Specific Data	Source	Purpose
Production plan	Ore tonnage and Cu, Au, Ag grades by year, 2026–2041	Mill 3Q26R2 plan	Physical basis; shifted under delay scenarios
Metallurgy	Cu recovery 84.7%, Au recovery 61.7%, payability factors	KL FS 2023; Mill 3Q26R2	Conversion of contained to payable metal
Cost profile	Annual development capital, sustaining capital, and operating cost, 2021–2041	Company planning file	Capital and operating cash outflows
Reserve and resource	381 Mt reserve at 0.99% Cu and 0.88 g/t Au	KL FS 2023	Life-of-mine context; licence extension case
Price and fiscal	Long-term Cu and Au planning prices; fiscal terms	FCX Form 10-K (2024)	Price, royalty, and tax assumptions
Ramp shape	Monthly and quarterly tonnage through 2030	UG Production Forecast 3Q26R2	Cross-check on ramp; forecast tracking

Source: Study model and underlying company planning data described in this manuscript.

Data Analysis

Phase 3 converts the mine plan into cash flow in seven steps: payable metal, revenue, operating cost, royalty with depreciation and tax, free cash flow, NPV and payback, and a real-versus-nominal reconciliation. NPV is the sum of discounted free cash flows over the licence period, and the real and nominal statements are linked by the Fisher relation:

$$\text{NPV} = \sum \text{CF}_t / (1 + r)^t, t = 2026, \dots, 2041; (1 + r_{\text{nominal}}) = (1 + r_{\text{real}}) \times (1 + \pi)$$

Phase 4 tests the base case in five steps: (4a) schedule scenarios of three months early, six months late, and twelve months late with a 10% overrun on remaining development capital, with production, operating cost, and capital shifting together against a fixed 2041 licence horizon; (4b) decomposition of the loss into deferral and truncation by relaxing the horizon to 2042; (4c) a six-case differential real escalation family; (4d) one-way sensitivity on ten inputs; and (4e) a two-way grid of schedule slip against copper price with breakeven. Phase 5 converts the scenario results into a per-month cost of delay and funds a protection measure when months avoided $\times$ probability of success (p) $\times$ cost of delay exceeds its present-value cost. Finally, a forecasting review (Jacobs & Chase, 2018) treats the base schedule as the forecast and the six-month slip as the actual, and computes the forecast error, running sum of forecast errors (RSFE), mean absolute deviation (MAD), and tracking signal:

$$E_t = A_t - F_t; \text{RSFE}_n = \sum E_t; \text{MAD}_n = \sum |E_t| \div n; \text{TS}_n = \text{RSFE}_n \div \text{MAD}_n$$

A control limit of ± 4 is applied, because about 99.9% of random errors lie within ± 4 MAD; a signal beyond it indicates bias

RESULTS AND DISCUSSION

Model Inputs and Base Case

All values are in real 2026 US dollars at a 10% real discount rate for 2026–2041. The 3Q26R2 plan follows a typical block-cave shape: 1.22 Mt of development ore in 2027, drawpoint production from 1 July 2029, 17 Mt by 2031, and full rate of 47.5 Mt per year (130,000 t/d) from 2035, totalling 469.1 Mt. Copper grade peaks at 1.51% in 2031, so any delay pushes the richest ore further out. The key assumptions are summarized in Table 2.

Table 2. Key Model Assumptions

Parameter	Value	Source
Copper / gold / silver price	US\$4.00/lb; US\$25.00/oz	FCX (2024) long-term planning basis
Payable factor (Cu / Au / Ag)	81.3% / 59.8% / 68.9% (recovery × payability)	KL FS 2023; Mill 3Q26R2
Development / sustaining capital	US\$4,161mm (2026–2033) / US\$1,383mm (2034–2041)	Company cost planning file
Operating cost	US\$4,760mm (2026–2041), entered year by year	Company cost planning file
Sunk capital	US\$1,139mm (2021–2025), excluded from NPV	Retained in depreciation base
Royalty and income tax	4% of gross revenue; 25% of taxable income	Simplified IUPKOP fiscal terms
Discount rate / inflation	10% real / 2.0% (nominal cross-check)	Company practice; FOMC (2025)
Evaluation period	2026–2041	IUPKOP licence horizon

Source: Study model and underlying company planning data described in this manuscript.

A worked example for 2035 shows gross revenue of US\$5,324 million and free cash flow of US\$3,398 million, contributing US\$1,310 million to NPV. Escalating all lines at 2.0% inflation and discounting at the Fisher-consistent 12.20% nominal rate gives the same contribution and the same project NPV, confirming that the base case is a real-terms model rather than a constant-price forecast. The base case yields an NPV of US\$9,408 million with payback in 2032 and annual free cash flow above US\$3.0 billion at full production. Because most revenue arrives in the second half of the licence period, the project is highly sensitive to timing.

Schedule Scenarios and Sources of Loss

Table 3. Schedule Scenario Results

Scenario	NPV (US\$mm)	ΔNPV (US\$mm)	ΔNPV (%)	Paybac k	Mined Ore (Mt)
Optimistic: 3 months early	9,794	+386	+4.10%	2031	469.1
Base case: on schedule	9,408	–	–	2032	469.1
Pessimistic: 6-month delay	8,743	(665)	–7.07%	2032	445.3
Worst case: 12-month delay and 10% capital overrun	7,839	(1,569)	–16.68%	2033	421.6

Source: Study model and underlying company planning data described in this manuscript.

Three points stand out. First, each month of delay costs about US\$111 million, almost linearly (US\$665 million at six months and US\$1,332 million at twelve months before overrun). If capital spending stayed on the original timeline, the cost would rise to US\$138 million per month, so US\$111 million is the lower bound of a US\$111–138 million range. Second, the effect is asymmetric: accelerating by a month is worth about US\$129 million. Third, under the current licence the loss is permanent, as 23.8 Mt of ore is stranded under a six-month delay and 47.5 Mt under a twelve-month delay. Table 4 decomposes the loss.

Table 4. Decomposition of the Delay Loss (US\$ million)

Mechanism	6-Month Delay	Share	12-Month Delay	Share
Deferral of cash flows (heavier discounting)	(428)	64%	(855)	64%
Truncation at the 2041 licence boundary	(238)	36%	(477)	36%
Total	(665)	100%	(1,332)	100%

Source: Study model and underlying company planning data described in this manuscript.

About two-thirds of the loss comes from discounting, which can only be avoided by staying on schedule, and one-third from truncation, which a licence extension would eliminate. Extending production at the 2041 rate to 2046 adds about US\$1,981 million, roughly 1.25 times the worst-case delay loss, making it the strongest argument in the study for pursuing the extension.

Differential Escalation, Sensitivity, and Breakeven

Table 5. Differential Real Escalation Family

Case	Real Cu	Real Au	Real Cost	NPV (US\$mm)	Δ vs Base	Cost of Delay (US\$mm/month)
Stagflation	−0.50%	0.00%	+2.00%	8,547	−9.2%	110
Cost squeeze	0.00%	0.00%	+2.00%	8,950	−4.9%	112
Costs rise, prices flat	0.00%	0.00%	+1.00%	9,188	−2.3%	111
Real-flat (base case)	0.00%	0.00%	0.00%	9,408	—	111
Reference escalation view	+0.50%	0.00%	+0.75%	9,666	+2.7%	113
Energy transition	+1.50%	+0.50%	+1.00%	10,714	+13.9%	119

Source: Study model and underlying company planning data described in this manuscript.

Project value is sensitive to differential escalation, with NPV spanning US\$2.2 billion, wider than the worst-case delay loss, so the base-case NPV should be quoted with this range. However, the cost of delay barely changes (US\$110–119 million per month), which makes it a robust management metric. The one-way sensitivity results are presented in Table 6.

Table 6. One-Way Sensitivity of Project NPV (US\$ million)

Variable	Range	Favourable	Adverse	Swing	Within Management Control?
Copper price	±15%	+1,385	(1,385)	1,385	No
Discount rate	±1 pp	+1,093	(975)	1,093	Partly, through financing
Real copper escalation	±1% p.a.	+862	(788)	862	No
Schedule	±6 months	+771	(665)	771	Yes
Gold price	±15%	+589	(589)	589	No
Real cost escalation	0 / +1.5% p.a.	–	(337)	337	Partly, through contracting
Copper payable factor	±3 pp	+341	(341)	341	Partly, through metallurgy
Development capital	±10%	+263	(263)	263	Yes
Operating cost	±15%	+187	(187)	187	Yes
Silver price	±15%	+53	(53)	53	No

Source: Study model and underlying company planning data described in this manuscript.

Copper price and the discount rate rank highest but are outside project control. Schedule ranks fourth overall and first among controllable variables, about three times larger than development capital and four times larger than operating cost, and it is the only controllable variable with a permanent downside. A three-point error in the copper payable factor (US\$341 million) also exceeds the development capital sensitivity. The two-way grid shows that a twelve-month delay at US\$5.00/lb copper still outperforms an on-schedule project at US\$4.00/lb, meaning that about 58 cents of copper price equals twelve months of schedule. The breakeven metal price factor is 0.304 (copper at US\$1.22/lb), rising only to 0.330 in the worst case, so the issue is how much value is captured, not whether value exists.

Discussion

The losses of 7.1% and 16.7% of base-case NPV are consistent with (Nesbitt et al., 2021), who show that schedule uncertainty substantially reduces underground mine value. KL is unusual because its fixed licence horizon converts deferred production into lost production, adding a truncation loss that open-ended assets do not face. The worst case reflects the megaproject pattern in which schedule and cost failures share the same planning optimism (Flyvbjerg, 2014). Expressing delay as about US\$111 million per month moves schedule discussions into capital-allocation terms and counters the persistence of optimistic assumptions in copper investment decisions (Auger & Guzmán, 2010). Because delay is far more likely than early completion, the pessimistic scenario is a more useful planning reference than the base case (Del Castillo & Dimitrakopoulos, 2019).

Schedule Protection: Cost-Benefit Assessment**Table 7.** Cost-Benefit Assessment of Schedule Protection Measures

Measure	PV Cost (US\$mm)	Months Avoided	Probability It Works	Expected Benefit (US\$mm)	Ratio	Decision
Buffer ore stockpile ahead of the mill	25	2	55%	122	4.9x	Fund
Milestone-linked contractor incentive and penalty contracts	80	3	50%	166	2.1x	Fund
Conditional schedule contingency reserve, released against leading indicators	40	2	35%	78	1.9x	Fund

Source: Study model and underlying company planning data described in this manuscript.

All three measures pass the funding rule, with the stockpile the clearest case. Because the measures overlap and may avoid less than the assumed delay, the ratios should be used to rank options rather than to predict returns. Schedule variance should be reported in both months and dollars.

Forecasting Review of the KL Plan

No model input comes from a time series because KL has no production history; the plan is a causal forecast, so its errors tend to be biased in one direction rather than random, which is the pattern a tracking signal is designed to catch. Under an annual review, the six-month slip produces a MAPE of 19.2% during the 2027–2034 ramp but only 0.6% on the plateau, and the RSFE settles at –23.7 Mt, matching the stranded ore in the DCF view. The review frequency determines how early the slip is detected (Table 8).

Table 8. Period in Which a Six-Month Slip Is Flagged, by Review Frequency

Review Frequency	Periods to Reach –4	Flagged In	Months After First Planned Tonnes	Cumulative Shortfall
Monthly	4	April 2027	4	0.32 Mt
Quarterly	4	Q4 2027	12	0.71 Mt
Annual	5	2031	60	8.66 Mt

Source: Study model and underlying company planning data described in this manuscript.

Monthly tracking flags the slip 27 months before production starts, while the protection measures can still be triggered; an annual review detects it only in 2031, after those decisions have passed. Implementation requires a frozen 3Q26R2 baseline that changes only through approved revisions, ownership by the KL planning team with quarterly reporting in tonnes, months, and dollars, and a three-band response ladder: report only within ± 2 , investigate and prepare measures between ± 2 and ± 4 , and a steering-committee decision within the month beyond ± 4 . From July 2029, a separate production-tonnes series should run alongside the development series. None of this requires new systems or staff.

CONCLUSION

The deterministic discounted cash flow (DCF) model estimated a base-case net present value (NPV) of US\$9,408 million for the Kucing Liar (KL) project at a 10% real discount rate, with a projected payback year of 2032 under the specified operating assumptions for 2026–2041. A six-month schedule delay reduced NPV by US\$665 million, while a 12-month delay combined with a 10% escalation in development capital expenditures resulted in an NPV reduction of US\$1,569 million. The estimated financial loss averaged approximately US\$111 million per month when capital expenditures were rescheduled in line with production, increasing to US\$138 million per month when capital expenditures could not be deferred. Approximately two-thirds of the delay-related NPV reduction was attributable to deferred cash flows, while the remaining portion resulted from production extending beyond the assumed mining license expiration in 2041. These findings demonstrated the financial significance of schedule performance and highlighted the importance of incorporating economic assessments into schedule-protection decisions. However, the estimated impacts remained sensitive to assumptions regarding metal prices, fiscal parameters, metallurgical recovery rates, discount rates, and the mining license expiration date (Morrow, 2011; Committee, 2025).

The findings provided a quantitative basis for evaluating schedule-risk mitigation measures by comparing their present costs with the estimated financial benefits of avoiding project delays. Project management should systematically monitor underground development progress against planned production milestones and periodically reassess mitigation strategies as updated operational and financial information becomes available. Future research should incorporate stochastic scheduling models to estimate delay probabilities, examine interactions among geological and construction-related risks, evaluate alternative mining license extension scenarios, and assess the sensitivity of projected ore production to updated mineral reserve and resource classifications. Additionally, independent validation of the accompanying DCF models would enhance the reproducibility, transparency, and reliability of the financial estimates, thereby strengthening their application to strategic investment and project management decisions.

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CONFLICT OF INTEREST

The author states that there are no conflicts of interest, whether personal, commercial, or financial, that can affect the implementation and results of this study.

AUTHOR CONTRIBUTION

Henry Trimukti Rahadian and Jagat Prirayani contributed to research design, data collection and processing, system development, result analysis, and article manuscript preparation.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

In the process of compiling this article, the author uses generative artificial intelligence (AI) as a tool in language refinement, writing structure, and grammar improvement. The use of AI is carried out on a limited basis and remains under the supervision of the author. All data, analysis, interpretation, and scientific substance in this article have been checked and verified by the author. The author is solely responsible for the accuracy, authenticity, and final content of the manuscript.

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