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ECONOMIC FEASIBILITY ASSESSMENT OF BULLDOZER REPLACEMENT: A LIFE CYCLE COST ANALYSIS APPROACH

PENILAIAN KELAYAKAN EKONOMI PENGGANTIAN BULLDOZER: PENDEKATAN ANALISIS BIAYA SIKLUS HIDUP

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ABSTRACT
Coal mining operations are highly dependent on the reliability of heavy equipment to ensure the smooth flow of materials from production areas to delivery facilities. In the stockpile area of PT XYZ, bulldozers play a crucial role in coal dozing, spreading, and leveling activities that support supply to the Train Loading Station (TLS). High operating intensity and abrasive environmental conditions accelerate component wear, increasing the risk of performance degradation. Historical data indicate an upward trend in maintenance costs and bulldozer downtime frequency, which negatively affects cost efficiency and operational reliability. To date, PT XYZ does not have a structured quantitative policy to determine the optimal timing for heavy equipment replacement, resulting in largely reactive replacement decisions that may lead to cost overruns and disruptions to coal delivery schedules. This study aims to evaluate the economic feasibility of bulldozer replacement in the stockpile area of PT XYZ using a techno-economic approach. A deterministic case study method is applied using operational and maintenance data from 2019–2025, along with five-year cost projections. The analysis employs Life Cycle Cost Analysis (LCCA) and Equivalent Uniform Annual Cost (EUAC), with future cash flows discounted using the company's Weighted Average Cost of Capital (WACC). The results show that although the existing unit exhibits declining annual capital costs, rising maintenance costs result in higher and more volatile total annual costs. In contrast, the new unit demonstrates lower and more stable EUAC, indicating that bulldozer replacement is the most economically efficient alternative.
Keywords: *Asset Replacement, Life Cycle Cost, Equivalent Uniform Annual Cost, Mining Equipment, Cost Efficiency*

ABSTRAK
Operasi penambangan batubara sangat bergantung pada keandalan alat berat untuk menjamin kelancaran aliran material dari area produksi ke fasilitas pengiriman. Di area stockpile PT XYZ, bulldozer berperan sangat penting dalam kegiatan dozing, spreading, dan leveling batubara yang mendukung pasokan ke Train Loading Station (TLS). Intensitas operasi yang tinggi serta kondisi lingkungan yang abrasif mempercepat keausan komponen, sehingga meningkatkan risiko penurunan kinerja. Data historis menunjukkan adanya tren peningkatan biaya perawatan dan frekuensi downtime bulldozer, yang berdampak negatif terhadap efisiensi biaya dan keandalan operasional. Hingga saat ini, PT XYZ belum memiliki kebijakan kuantitatif yang terstruktur untuk menentukan waktu penggantian alat berat yang optimal, sehingga keputusan penggantian masih bersifat reaktif dan berpotensi menimbulkan pembengkakan biaya serta gangguan terhadap jadwal pengiriman batubara. Penelitian ini bertujuan untuk mengevaluasi kelayakan ekonomi penggantian bulldozer di area stockpile PT XYZ dengan menggunakan pendekatan techno-economic. Metode yang digunakan adalah studi kasus deterministik dengan memanfaatkan data operasional dan perawatan periode 2019–2025, serta proyeksi biaya untuk lima tahun ke depan. Analisis dilakukan menggunakan Life Cycle Cost Analysis (LCCA) dan Equivalent Uniform Annual Cost (EUAC), dengan arus kas masa depan didiskontokan menggunakan Weighted Average Cost of Capital (WACC) perusahaan. Hasil penelitian menunjukkan bahwa meskipun unit eksisting memiliki biaya modal tahunan yang menurun, peningkatan biaya perawatan menyebabkan total biaya tahunan menjadi lebih tinggi dan tidak stabil. Sebaliknya, unit baru menunjukkan nilai EUAC yang lebih rendah dan stabil, sehingga penggantian bulldozer merupakan alternatif yang paling efisien secara ekonomi.
Kata Kunci: Penggantian Aset, Biaya Siklus Hidup, Biaya Tahunan Equivalent, Alat Berat Tambang, Efisiensi Biaya

INTRODUCTION

PT XYZ, a prominent Indonesian mining and energy corporation, currently faces a strategic crisis at its stockpile area, where aging bulldozer fleets have become a critical bottleneck in the coal supply chain. These machines are essential for dozing and spreading activities, yet the company's lack of a formal replacement policy has resulted in units remaining in service long past their prime, leading to a "reactive" maintenance culture. As Liu et al. (2020) emphasize, "making accurate decisions to replace equipment based on Life Cycle Cost assessment is a cost-effective way for reducing the risk of downtime." Currently, PT XYZ's data shows a trend of rising maintenance costs and prolonged equipment downtime, which directly threatens the continuity of coal shipments. This situation underscores the principle that "identifying the optimal time for equipment replacement is important for lowering life-cycle costs while ensuring an appropriate machine availability level" (Al-Chalabi, 2014). The core of the issue lies in the "U-shaped" Life Cycle Cost curve, where equipment eventually becomes "prohibitively costly to operate past a point, most generally in an age which is known as the optimal economic life."

To address these inefficiencies, PT XYZ is shifting toward a systematic, data-driven approach to asset management, moving beyond simple production targets to prioritize long-term cost efficiency. By utilizing methodologies such as Life Cycle Cost Analysis (LCCA) and Equivalent Uniform Annual Cost (EUAC), the company aims to determine the optimal economic life of its fleet, effectively comparing the "defender" (existing units) against the "challenger" (new units). Recent studies in the sector, such as those by Castañón et al. (2024), affirm that "diminishing equipment efficacy was strongly associated with rising maintenance expenses and reduced production efficiency." This transition is not merely technical but strategic; it allows PT XYZ to align its capital expenditure (CAPEX) with its mission of sustainability and operational reliability. Ultimately, adopting a proactive replacement strategy informed by historical data such as labor hours, salvage value, and downtime frequency is essential for PT XYZ to maintain its competitive edge in a volatile coal market and ensure that "capital allocation aligns with the principles of cost efficiency and operational sustainability."

LITERATURE REVIEW

Heavy Equipment in Mining Operations

In the coal supply chain of PT XYZ, the bulldozer acts as a critical mechanical link, performing "dozing and spreading operations to shape, level, and arrange coal piles" to ensure material readiness. Its role is most strategic in facilitating the material flow to the Train Loading Station (TLS), where it supplies coal to vibrating feeders and conveyor systems. Because this operation is central to daily delivery performance, any equipment failure is a "direct intrusion into the continuity of coal transportation," resulting in both immediate repair expenses and significant financial losses from production delays. This operational pressure is compounded by a "harsh and highly abrasive" stockpile environment defined by unstable surfaces and high moisture that demands high-intensity service of 12–13 hours per day, leading to accelerated wear on the undercarriage and hydraulic systems.

This high-intensity usage triggers a natural process of "aging and reliability deterioration," where mechanical components undergo progressive degradation until the unit is no longer economical to operate. As Endrenyi and

Anders (2006) explain, while predictive strategies can extend service life, "preventive and predictive maintenance strategies... cannot completely halt the natural degradation process." Consequently, PT XYZ faces a "reliability cost trade-off" where additional maintenance only sustains performance up to a point before costs exceed operational benefits. This leads to a non-linear cost escalation model, particularly as equipment enters the "wear-out phase," where the risk of repeated failures increases.

The financial burden of maintaining these aging assets is further magnified by the "indirect economic impact in the form of lost production." Utilizing the Overall Mining Equipment Effectiveness (OMEE) model, experts note that "diminishing equipment efficacy was strongly associated with rising maintenance expenses and reduced production efficiency" (Gutiérrez-Diez et al., 2024). According to Reliability-Centered Maintenance (RCM) principles, "downtime in critical equipment should be treated as an economic cost because it reduces the value generated by the operation" (Moubray, 1997). For PT XYZ, this means the rising frequency of downtime is not just a technical failure but a primary financial indicator that the bulldozer has likely reached the end of its "optimal economic life," necessitating a structured replacement decision to safeguard the company’s supply chain efficiency

Asset Life Concept

In asset management, an equipment unit’s "life story" is defined by three intersecting dimensions Technical, Economic, and Profit Life each providing a different lens on when a machine truly becomes a liability. For the bulldozers at PT XYZ, Technical Life represents the physical threshold (estimated at 30,000 to 40,000 hours) before structural failure becomes irreversible. However, remaining technically "alive" does not equate to performance; as a unit approaches this limit, fuel consumption spikes and reliability plummets. This shift transitions the focus to Economic Life, the strategic point where the total annual cost a combination of declining ownership costs and rising maintenance expenses reaches its lowest point on the U-shaped cost curve. As noted in the literature, equipment often reaches a stage where it remains technically viable but is no longer economically efficient, leading to a "false economy" if maintenance continues.

Beyond the purely financial costs of repairs lies Profit Life, the period during which the bulldozer still generates net added value. When a unit at PT XYZ can no longer maintain a consistent material flow to the Train Loading Station (TLS), it has likely outlived its profit life. At this stage, downtime is no longer just a repair bill; it is "lost production" that disrupts delivery schedules and revenue. While PT XYZ has utilized overhauls to extend the technical life of its fleet, Sullivan et al. (2016) caution that such interventions "only repair specific components" and "do not stop long-term structural degradation." Consequently, an overhaul may provide a temporary "new lease of life," but it does not fundamentally reverse the rising trajectory of the U-shaped curve or significantly extend the asset's economic life.

Asset Replacement Theory

In the high-stakes environment of mining, asset replacement theory provides the necessary shift from intuitive guesswork to data driven strategy. At the core of this framework are Deterministic and Stochastic models. For PT XYZ's stockpile bulldozers, deterministic models are particularly effective because maintenance costs and reliability trends follow a "fairly consistent pattern," allowing the use of Life Cycle Cost Analysis (LCCA) to predict future conditions. While stochastic models offer higher precision by using Monte Carlo simulations and probability distributions to account for "difficult-to-predict external factors" (Dekker, 1996), the deterministic approach remains the industry standard in Indonesia due to its practical application in rapid operational decision-making.

A critical tool in this analysis is the Equipment Replacement Planning Cost (EPC) model, which integrates ownership, maintenance, and downtime costs into a single annual measure. This allows for a direct comparison between the "Defender" (the aging unit) and the "Challenger" (the potential replacement). As Cesca & Novaes (2020) note, the EPC model is vital for bulldozers because it accounts for "maintenance cost escalation" and the "time value of money." To trigger a replacement, management looks for specific thresholds:

- Economic: When the Defender's annual cost exceeds the Challenger's.
- Maintenance: When repair costs reach 50%–60% of the total annual equipment cost (Barringer, 1997).
- Reliability: When the probability of failure surpasses operational tolerance, threatening the "continuity of the production process."

In the specific context of PT XYZ, these theoretical models must be adjusted for mining-specific stressors. The "abrasive and heavy conditions" of coal handling, combined with intense utilization of 12–13 hours per day, significantly "accelerate the wear-out phase" (Jardine & Tsang, 2013). This means the economic life of these bulldozers is often shorter than their technical life. Furthermore, because these units are "key drivers in the production chain," any downtime has a direct correlation with reduced output at the Train Loading Station (TLS). Ultimately, a structured replacement policy ensures that capital allocation is not just a reactive expense but a strategic move to optimize Overall Mining Equipment Effectiveness (OMEE) and maintain long-term safety and compliance.Life

Cycle Cost Analysis (LCCA)

In the mining industry, Life Cycle Cost Analysis (LCCA) serves as a comprehensive "engineering economic analysis method" that evaluates the total financial burden of an asset throughout its entire tenure from initial acquisition to final disposal. For PT XYZ, LCCA is the primary tool to move beyond simple repair bills and understand the Total Cost of Ownership (TCO) by accounting for the "time value of money" to accurately compare the Defender (the aging bulldozer) against the Challenger (a new unit). The LCCA framework is built upon four foundational cost pillars: Capital Costs, which include the initial purchase minus the Salvage Value; Operating Costs, dominated by fuel consumption which, as Kheirkhah et al. (2018) identify, is a "dominant contributor" that increases as engine efficiency degrades; Maintenance and Repair Costs, which tend to rise exponentially as the undercarriage and hydraulic systems enter the "wear-out phase"; and Downtime Costs (DTC), which represent the "lost productivity" or the economic loss incurred when coal flow to the Train Loading Station (TLS) is interrupted.

As equipment ages, these cost components interact dynamically, often forming a U-shaped curve where the diminishing capital depreciation is eventually overtaken by the rapid escalation of repair and downtime expenses. Following the principles of Moubray (1997), downtime on critical assets must be treated as a direct economic cost because it reduces the overall value generated by the operation. Because "there is no universal model for LCCA," as noted by Kheirkhah et al. (2018), PT XYZ must adapt these components to its specific "harsh and abrasive" stockpile environment, where high-intensity usage of 12–13 hours per day accelerates technical degradation. Ultimately, this structured analysis provides the scientific justification for replacement, ensuring that PT XYZ avoids the "false economy" of maintaining an asset that is technically operational but economically ruinous.

Time Value of Money (TVM)

In the realm of strategic asset management, the Time Value of Money (TVM) is the mathematical bridge that allows PT XYZ to compare immediate capital investments with long-term operational expenses. As noted by Wu et al. (2019), money today is inherently more valuable than the same amount in the future due to its earning potential and the eroding effects of inflation. In a Life Cycle Cost Analysis (LCCA), this principle requires all future cash flows—such as maintenance spikes in year five or salvage values in year ten—to be converted into a Present Value (PV) using a specific discount rate *i* and time period *n* , expressed as:

$$PV = \frac{FV}{(1+i)^n}$$

This ensures that the "defender" and "challenger" are compared on a level playing field. While Future Value (FV), calculated as $FV = PV(1 + i)^n$, is essential for estimating the residual salvage value of a bulldozer at the end of its life, the most critical metric for equipment replacement is the Capital Recovery Factor (CRF). The CRF, defined as:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

allows the company to transform the total Net Present Value into an Equivalent Uniform Annual Cost (EUAC). This conversion is vital for PT XYZ because it provides a stabilized "annual figure" that accounts for both the massive upfront acquisition cost and the escalating maintenance fees, effectively revealing the true annual cost of ownership over different machine lifespans (Wu et al., 2024).

Weighted Average Cost of Capital (WACC)

In the financial evaluation of PT XYZ's asset strategy, the Weighted Average Cost of Capital (WACC) serves as the critical "hurdle rate" that defines the true cost of funding a new bulldozer. According to Frank & Shen (2016), WACC represents the proportional cost of all capital sources, balancing both equity (*E*) and debt (*D*). The formula accounts for the cost of equity(k_e), the interest on debt (k_d), and the tax shield (1 - *t*), which is vital for mining corporations with high capital intensity:

$$WACC = \left(\frac{E}{V} \times k_e\right) + \left(\frac{D}{V} \times k_d \times (1-t)\right)$$

Using WACC as the discount rate for Life Cycle Cost (LCC) and Equivalent Uniform Annual Cost (EUAC) calculations ensures that the bulldozer replacement analysis is grounded in PT XYZ's actual market reality. As Dobrowolski et al. (2022) assert, WACC internalizes macroeconomic risks such as inflation and interest rate fluctuations providing a precise measure to determine if a project creates or destroys shareholder value. If the "challenger" (new bulldozer) generates savings that exceed this hurdle rate, the investment is deemed economically rational. For PT XYZ, this involves a three-step implementation: first, calculating all future operation and maintenance cash flows; second, discounting those costs to their Present Value using the WACC; and finally, converting that total into an EUAC to reveal the most cost-effective alternative while accounting for the company's financial risk profile.

Equivalent Uniform Annual Cost (EUAC)

In the strategic management of PT XYZ's fleet, the Equivalent Uniform Annual Cost (EUAC) serves as a sophisticated economic engine that translates the complex, multi-year life cycle of an asset into a single, directly comparable annual figure. By applying the Capital Recovery Factor (CRF) to the total present worth of an asset including acquisition, maintenance, and salvage value EUAC provides the "temporal normalization" required to compare a "Defender" (the aging unit) with a "Challenger" (the new unit) on an "apples-to-apples" basis, regardless of their differing lifespans. As emphasized by Du Plessis (2014), the fundamental decision rule for PT XYZ is that replacement becomes mandatory when $EUAC_{Defender} > EUAC_{Challenger}$, signaling that the existing bulldozer has passed its optimal economic life and is now incurring "prohibitively costly" repair and downtime expenses. This methodology effectively balances the declining cost of ownership against the escalating costs of operation and undercarriage wear, transforming technical field data into a strategic investment policy that ensures the continuous flow of coal to the Train Loading Station (TLS) while safeguarding corporate capital efficiency.

Conceptual Framework

The conceptual framework for this study establishes a logical bridge between the operational challenges at PT XYZ and a strategic, data driven solution for asset management. Currently, the company's bulldozer fleet is trapped in a cycle of "reactive" maintenance, where increasing operating hours have led to skyrocketing costs and frequent unplanned downtime, yet no standardized replacement policy exists. This research fills that gap by integrating technical performance indicators such as mechanical availability and productivity decline with financial metrics through a comprehensive Life Cycle Cost (LCC) framework. By applying PT XYZ's Weighted Average Cost of Capital (WACC) as a discount rate and utilizing the Equivalent Uniform Annual Cost (EUAC) method, the model provides a rigorous "apple-to-apple" comparison between the current "Defender" units and potential "Challenger" replacements. The ultimate objective is to pinpoint the optimal economic replacement time, thereby transforming the company's asset strategy from a reactive burden into a proactive, sustainable model that minimizes long-term expenditure and stabilizes the coal supply chain.

RESEARCH METHODOLOGY

Research Design

This study employs a descriptive quantitative research design centered on engineering economic analysis to objectively evaluate the replacement feasibility of PT XYZ's stockpile bulldozers. By integrating Life Cycle Cost Analysis (LCCA) and Equivalent

Uniform Annual Cost (EUAC), the methodology establishes a standardized framework for comparing the "Defender" (existing units) against a "Challenger" (new replacement) over a five-year analytical horizon.

The LCCA captures the comprehensive financial footprint incorporating capital acquisition, operational fuel costs, escalating maintenance, and terminal salvage value while the EUAC transforms these multi-year totals into a single, annualized figure for "apple-to-apple" comparison. Adopting a deterministic modeling approach, the research utilizes historical data trends to project future costs under stable assumptions, ensuring that the final recommendation provides a mathematically grounded path to move PT XYZ from reactive maintenance to a proactive, strategic investment policy.

Object of Study and Analysis Scope

The object of this study is a Caterpillar D5R2XL bulldozer, a mission-critical asset responsible for maintaining the coal material flow to the Train Loading Station (TLS) at PT XYZ. To address the company's need for a quantitative replacement strategy, the analysis establishes a five-year scope (2026–2030) to evaluate two distinct scenarios: maintaining the "Defender" (the existing unit) versus investing in a "Challenger" (a new replacement unit). This scope focuses specifically on cost-differentiating variables, including the Challenger's capital expenditure, fuel consumption patterns, terminal salvage values, and the heavy maintenance requirements characteristic of stockpile work specifically overhauls and undercarriage replacements. By excluding fixed costs like operator wages, the study maintains a sharp focus on the economic feasibility of the two alternatives. While the research is bound by the limitations of a deterministic model relying on 2020–2024 historical data and assuming constant variables for inflation and fuel prices it provides a structured five-year projection that aligns with PT XYZ's medium-term planning and corporate investment policies.

Data Collection and Data Sources

This research relies exclusively on secondary data extracted from PT XYZ's official operational and financial repositories to ensure a high degree of accuracy and alignment with corporate budgeting standards. The data collection framework spans four primary categories: Operational Records (2019–2025), which provide historical trends for working hours and fuel consumption; Maintenance Planning Data, detailing the specific costs for preventive measures, overhauls, and the wear-intensive replacement of undercarriage components; Corporate Financial Metrics, including the Weighted Average Cost of Capital (WACC), terminal salvage values, and the capital expenditure (CAPEX) required for a new unit; and finally, Vendor Technical Specifications, which offer performance benchmarks for the "Challenger" unit's fuel efficiency and expected component lifespans. By synthesizing these diverse datasets, the study builds a robust quantitative foundation for the Life Cycle Cost (LCC) and Equivalent Uniform Annual Cost (EUAC) models, ensuring that the replacement analysis reflects the actual abrasive working conditions and financial realities of PT XYZ's stockpile operations.

Analytical Framework and Research Flow

This chapter presents a structured analytical framework for evaluating the bulldozer replacement decision using engineering economic principles. The study begins by analyzing historical operational and maintenance data to establish a reliable baseline, which is then projected over a five-year planning horizon. Life Cycle Cost Analysis (LCCA) is applied to both the existing bulldozer (defender) and the replacement option (challenger), incorporating all relevant cost components such as capital cost, fuel, maintenance, repairs, overhauls, undercarriage replacement, and salvage value while excluding non differential costs like operator wages and overheads. All projected cash flows are discounted using the company's Weighted Average Cost of Capital (WACC) to reflect the time value of money and ensure consistency with capital budgeting practices. The resulting life cycle costs are converted into Equivalent Uniform Annual Cost (EUAC), which serves as the main decision criterion, with the lower EUAC indicating the more economical option. Cost projections follow a deterministic, trend-based, and plan-oriented approach grounded in historical data, OEM specifications, and maintenance plans. By aligning methodology, assumptions, and decision metrics with the research questions, the framework provides a transparent and objective basis for determining the most cost-efficient bulldozer replacement strategy.

RESULTS AND DISCUSSION

Description of the Object of Study and Operational Context

In the operational ecosystem of PT XYZ, the Caterpillar D5R2XL bulldozer functions as a "secondary production critical asset" whose performance is vital to the integrity of the entire coal delivery system. Operating as a strategic buffer in the stockpile area, this unit ensures that coal dozing and rehandling activities maintain the necessary reclaim rates to support the downstream Train Loading Station (TLS). Despite not being a primary extraction unit, any failure in this area creates a ripple effect that hampers material flow and compromises loading performance.

The bulldozer faces a grueling operational profile characterized by short, repetitive working cycles and continuous contact with abrasive coal types, which significantly accelerates wear on the undercarriage and causes operating hours to accumulate at a much higher rate than standard industrial applications. Consequently, the decision to replace this unit must move beyond isolated financial metrics to account for its systemic role in preventing bottlenecks; a failure at the stockpile "leaves assessment behind" and disrupts the rhythm of the entire supply chain, making reliability-centered replacement a necessity for sustaining corporate delivery targets.

Historical Operational and Maintenance Data Analysis (2019-2025)

The analysis of the Caterpillar D5R2XL bulldozer's historical data from 2019 to 2024 reveals the empirical reality of operating heavy equipment in the abrasive environment of a coal stockpile. By evaluating actual operating behavior and maintenance patterns, this section identifies the specific "inflection points" where mechanical reliability began to falter under the pressure of severe working conditions. These historical trends encompassing fuel consumption spikes, escalating repair frequencies, and the rapid wear of undercarriage components provide the quantitative foundation necessary to move beyond theoretical models. Ultimately, this retrospective look at the unit's performance establishes the "baseline cost" of the Defender, ensuring that the subsequent life cycle cost projections are grounded in the documented operational challenges and financial burdens experienced by PT XYZ over the past six years.

Operating Hours and Utilization Pattern

The historical analysis of the Caterpillar D5R2XL bulldozer from 2019 to 2025 reveals a classic equipment "wear-out" profile, where intensive utilization has led to severe reliability degradation. Between 2020 and 2023, the unit was a workhorse, averaging nearly 4,100 working hours annually with a peak Mechanical Availability (MA) of 88.54% in 2022. However, this high-intensity service under abrasive stockpile conditions characterized by short, repetitive cycles triggered a critical inflection point in 2024. During this year, MA plummeted to 55.23% as downtime surged to 1,576 hours, signaling that the unit had transitioned from stable operation to a state of chronic technical failure. By 2025, the unit reached a functional standstill with 0% availability, effectively concluding its reliable service life.

The financial data mirrors this technical decline, illustrating a shift from "preventive" to "reactive" spending. While preventive maintenance costs remained stabilized by contract structures (approx. Rp 321–411 million), repair costs escalated exponentially, skyrocketing from Rp 1.79 billion in 2020 to a staggering Rp 4.06 billion in 2025. This escalation was driven by a high concentration of major overhauls; within just six months in 2024, the unit required both a final drive and a general overhaul, culminating in a massive Rp 3.56 billion multi-component repair in early 2025. This "repair cluster" indicates diminishing returns, where massive capital injections are required simply to achieve basic functionality.

Furthermore, the unit's operational efficiency has steadily eroded, as evidenced by the Fuel Rate Trend. The fuel consumption rate rose consistently from 18.29 L/hour in 2019 to 23.00 L/hour by 2025, a nearly 26% increase in fuel intensity. This rising rate, coupled with the "reliability-cost trade-off," confirms that the bulldozer is no longer just a maintenance burden but an energy-inefficient liability. These empirical findings rising fuel rates, concentrated major repairs, and the collapse of mechanical availability provide the definitive quantitative baseline for the Life Cycle Cost Analysis (LCCA), suggesting that the "Defender" has clearly exceeded its optimal economic life.

Projection Assumption Overview

The projection assumptions for the 2026–2030 period establish a "level playing field" by fixing both units to a consistent 400-hour monthly utilization under identical abrasive stockpile conditions, thereby isolating asset efficiency as the primary cost driver. A stark divergence emerges in fuel performance, where the Defender's fuel rate is projected to climb from 22.83 L/hour to 25.46 L/hour due to mechanical wear, while the Challenger maintains an optimal, OEM-backed rate of 14.8 L/hour, shielding the company from the full impact of the 3.5% annual fuel price inflation.

This efficiency gap is compounded by corrective maintenance strategies; whereas the Challenger benefits from a stable, "infant-stage" lifecycle with minimal repair needs, the Defender is burdened by the "wear-out phase," requiring three major overhauls and triennial undercarriage replacements that peak at Rp 1.79 billion per event. These projections provide a definitive answer to RQ1 and RQ2 by illustrating that the Defender has entered a phase of diminishing returns with escalating, unstable costs, while the Challenger offers a superior, predictable economic profile through significant fuel savings and reduced repair frequency.

Life Cycle Cost Analysis

The five-year Life Cycle Cost (LCC) analysis from 2026 to 2030 reveals a definitive economic divergence between the aging Defender and the proposed Challenger at PT XYZ. The Defender carries a staggering total cost of *IDR 25,711,354,435.29*, a figure driven by the relentless "wear-out phase" that necessitates repetitive major repairs and undercarriage overhauls peaking at over IDR 7 billion in the final year. In stark contrast, the Challenger presents a more efficient total cost of *IDR 18,288,935,121.53*; although it requires a substantial initial capital investment of IDR 5.74 billion, its vastly superior fuel efficiency and minimal corrective maintenance requirements yield a more stable and lower overall financial burden. When the Time Value of Money is applied through Present Value (PV) calculations, the Challenger's streamlined operational cost structure which avoids the "repair clusters" of the older unit clearly outperforms the Defender. These findings confirm that the Defender has become a "maintenance liability," and replacing it with the Challenger is the financially superior strategy, offering PT XYZ significant medium term savings and enhanced operational reliability.

Equivalent Uniform Annual Cost (EUAC)

The final stage of the economic evaluation involves calculating the Equivalent Uniform Annual Cost (EUAC), a process that normalizes the total Life Cycle Cost into comparable yearly units using the Capital Recovery Factor (CRF). Based on PT XYZ's WACC of 12.10% over a five-year analysis horizon, the CRF effectively acts as a mathematical bridge to distribute capital and operational burdens across the asset's lifespan. The calculation results reveal a decisive advantage for the Challenger: the Defender carries a total annualized burden of *Rp 12,421,410,292.43*, driven largely by escalating fuel consumption and the "repair clusters" of major overhauls and undercarriage replacements. In contrast, the Challenger's total annualized cost is significantly lower at Rp 10,961,546,362.61, even after accounting for the substantial capital recovery of the initial investment. This comparison provides the ultimate quantitative answer to the study: by replacing the aging Caterpillar D5R2XL, PT XYZ stands to realize an annual economic benefit of approximately Rp 1.46 billion, proving that the Challenger is the more financially efficient and sustainable choice for stockpile operations.

Defender vs Challanger Comparison EUAC

The ultimate comparison between the Defender and Challenger through the Equivalent Uniform Annual Cost (EUAC) lens confirms a classic engineering economics trade-off: while the Defender requires zero capital expenditure, its astronomical operating and maintenance burdens far outweigh the cost of a new investment. The Defender has entered a terminal wear-out phase, marked by a volatile cost structure where "repair clusters" specifically recurring undercarriage overhauls and major component failures create a "money pit" scenario. Conversely, the Challenger's profile is dominated by capital recovery costs, yet it achieves superior efficiency through an optimal fuel rate and a stable, predictable maintenance schedule. By selecting the Challenger, PT XYZ effectively trades high-risk, escalating operational expenses for a controlled capital investment, resulting in a significantly lower annualized cost. Ultimately, the data supports an immediate replacement strategy; delaying this transition would only expose the company to further cost escalation and the growing risk of stockpile downtime, which could paralyze the material flow to the Train Loading Station (TLS).

CONCLUSION AND RECOMMENDATION

Conclusion

The study concludes that the Caterpillar D5R2XL bulldozer at PT XYZ has definitively surpassed its optimal economic life, transitioning into a terminal wear-out phase where escalating repair costs and fuel inefficiency yield diminishing returns. While the "Defender" requires no new capital, its five-year Life Cycle Cost (LCC) is significantly higher than that of a "Challenger" due to a "repair cluster" of major overhauls and a 26% increase in fuel intensity. By applying the Equivalent Uniform Annual Cost (EUAC) method, the research proves that the higher initial investment of a new unit is more than offset by its stable, predictable, and lower operating expenses. Consequently, replacing the unit is not only financially feasible but strategically essential; it allows PT XYZ to transform a volatile maintenance liability into a reliable asset, thereby safeguarding the coal flow to the Train Loading Station (TLS) and optimizing medium-term capital efficiency.

Recommendation

o maximize the strategic impact of these findings, it is recommended that PT XYZ officially adopt Life Cycle Cost Analysis (LCCA) and Equivalent Uniform Annual Cost (EUAC) as the standard financial gatekeepers for all future heavy equipment replacement decisions. This transition from reactive, hour-based replacement to a mathematically grounded "economic life" model allows the company to identify the exact point where an asset's rising operational costs exceed the cost of new capital. Furthermore, because this analytical framework is built on universal engineering economic principles, it should be scaled across PT XYZ's broader fleet including excavators, dump trucks, and loaders to create a unified, data-driven procurement strategy. By integrating these quantitative tools into the annual budget planning (RKAP), the company can proactively mitigate the risks of "repair clusters" and fuel inefficiency, ensuring long-term operational sustainability and optimized capital allocation across the entire organization.

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