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ENHANCING COAL SUPPLY PERFORMANCE THROUGH LEAN COAL FLOW AND STOCKPILE CAPACITY OPTIMIZATION

MENINGKATKAN KINERJA PASOKAN BATU BARA MELALUI ALIRAN BATU BARA YANG HEMAT DAN OPTIMASI KAPASITAS PENYIMPANAN

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ABSTRACT
This study evaluates the coal supply operations at a mine-mouth power plant that faces operational challenges due to increasing production and fluctuating demand, which have led to limited stockpile capacity and inefficient coal flow. By integrating safety stock analysis, livestock capacity planning, and lean management principles, the research identifies that the current fixed safety stock benchmark of 100,000 tons will be insufficient by 2027, requiring an increase to 171,194 tons/month to maintain a 95% service level. The findings reveal that the existing livestock capacity of 230,000 tons is inadequate for future needs, necessitating an expansion to approximately 764,108 tons to accommodate rising throughput and eliminate the need for costly temporary stockpiles and double handling. Implementing these structural improvements and reconfiguring the system to a direct coal flow is projected to reduce hauling distances by 0.6 km per ton, resulting in substantial operational cost savings of approximately Rp317.5 billion per year until 2027. Ultimately, this research provides an integrated framework that demonstrates how aligning physical infrastructure with lean principles can achieve sustainable economic benefits and ensure a more reliable coal supply chain.
Keywords: *Coal Supply, Safety Stock, Stockpile Capacity, Coal Flow, Cost Efficiency, Lean.*

ABSTRAK
Penelitian ini mengevaluasi operasional pasokan batubara pada pembangkit listrik tenaga uap (*mine-mouth*) yang menghadapi tantangan operasional akibat peningkatan produksi dan permintaan yang fluktuatif, yang menyebabkan keterbatasan kapasitas *stockpile* dan aliran batubara yang tidak efisien. Dengan mengintegrasikan analisis *safety stock*, perencanaan kapasitas *livestock*, dan prinsip manajemen *lean*, penelitian ini mengidentifikasi bahwa tolok ukur *safety stock* tetap sebesar 100.000 ton saat ini tidak akan mencukupi pada tahun 2027, sehingga memerlukan peningkatan menjadi 171.194 ton/bulan untuk menjaga tingkat layanan 95%. Temuan penelitian mengungkapkan bahwa kapasitas *livestock* yang ada saat ini sebesar 230.000 ton tidak memadai untuk kebutuhan masa depan, sehingga memerlukan ekspansi hingga kurang lebih 764.108 ton untuk mengakomodasi peningkatan *throughput* serta menghilangkan kebutuhan akan *temporary stockpile* yang berbiaya tinggi dan penanganan ganda (*double handling*). Implementasi perbaikan struktural ini dan rekonfigurasi sistem menjadi aliran batubara langsung diproyeksikan dapat mengurangi jarak angkut sebesar 0,6 km per ton, yang menghasilkan potensi penghematan biaya operasional yang signifikan sekitar Rp317,5 miliar per tahun hingga tahun 2027. Pada akhirnya, penelitian ini memberikan kerangka kerja terintegrasi yang menunjukkan bagaimana penyelarasan infrastruktur fisik dengan prinsip *lean* dapat mencapai manfaat ekonomi yang berkelanjutan dan memastikan rantai pasok batubara yang lebih handal.
Kata kunci: Pasokan Batubara, Safety Stock, Kapasitas Stockpile, Aliran Batubara, Efisiensi Biaya, Lean.

INTRODUCTION

The coal supply chain at PT XYZ is currently defined by a fundamental structural mismatch between fixed production and volatile consumption. While mining operations at the ABC Pit maintain a stable output of approximately 300,000 tons per month to satisfy contractual obligations, the PLTU X power plant exhibits fluctuating demand patterns due to its early-stage commissioning and unstable electricity requirements. This lack of synchronization creates a ripple effect throughout the logistics chain, as the system struggles to absorb surplus coal during periods of low demand or provide adequate buffers during peak consumption.

This operational strain is intensified by physical infrastructure limitations, specifically the limited capacity of the primary "Livestock" stockpile. Because the current storage area can only accommodate 230,000 tons, any excess production must be diverted to a Temporary Stockpile (TS). This results in "double handling" a process involving redundant hauling stages and increased equipment utilization that escalates logistics costs and operational complexity without adding value to the final product. Looking toward 2027, PT XYZ's Long-Term Corporate Plan (RJPP) projects a near doubling of coal throughput, which will place unprecedented pressure on existing inventory policies. The current safety stock benchmarks, established under lower-volume assumptions, are no longer sufficient to protect against future variability. Consequently, a strategic redesign of internal systems including a recalculation of safety stocks and a physical expansion of stockpile capacity is essential to mitigate the risks of coal degradation, spontaneous combustion, and supply disruptions that could impact national energy security.

LITERATURE REVIEW

Theoretical Foundation

This research is anchored in a multidimensional framework that integrates Inventory Management, Capacity Management, and Lean Principles to evaluate the stability and economic viability of coal supply systems. At its core, the study utilizes classical inventory theory to navigate the "trade-off between holding costs and shortage risks," positing that inventory should function as a strategic buffer to absorb demand variability and lead-time uncertainty (King, 2011). Central to this analysis is the calculation of Safety Stock (SS), which is mathematically determined by the interaction of service level (Z-score), demand fluctuations, and the specific lead times associated with mining cycles including digging, loading, and hauling durations.

The framework further asserts that inventory strategies cannot exist in a vacuum; they must be supported by robust Capacity Management. As Carpenter (1999) emphasizes, storage infrastructure must be designed to accommodate not just average stock, but peak levels driven by flow variability to avoid the "indirect costs" of congestion and repeated handling. This is synthesized through Lean Management philosophy, which identifies excessive handling and surplus stock as "non-value-adding activities" or waste (Mikhalchenko et al., 2016). By aligning these three pillars, the study establishes an integrated model for Cost Efficiency, demonstrating that sustainable economic benefits are achieved when physical capacity and safety stock levels are optimized to eliminate operational bottlenecks and minimize the total system cost.

Conceptual Framework

This conceptual framework serves as a strategic roadmap, bridging the gap between current operational constraints and a future state of optimized efficiency. By integrating safety stock management, capacity planning, and lean principles, the framework addresses the "structural mismatch" caused by rising production and PLTU consumption. It moves the system from a reliance on costly temporary storage and "double handling" toward a streamlined, "direct coal flow" model.

This systematic transition is designed to improve reliability and cost-efficiency, ensuring that infrastructure growth aligns with throughput demands in a sustainable manner.

RESEARCH METHODOLOGY

Research Design

This research employs a quantitative methodology to provide an objective, data-driven analysis of coal flow, stockpile capacities, and cost structures. By utilizing historical operational data and mathematical simulations, the study generates measurable insights and allows for scenario testing without disrupting continuous supply operations. The research design follows an integrative sequence: first, calculating safety stock requirements through 2027; second, modeling required stockpile capacity based on projected production and consumption growth; and finally, performing a cost-benefit analysis to ensure economic feasibility. Ultimately, this approach synthesizes inventory theory and lean principles to deliver "accurate, measurable, and objective insights" that transition the system from subjective policy making to a rigorous, theoretically grounded framework for real-world decision making

Data Collection Method

To optimize the coal supply chain and stockpile management, this study utilizes a dual layered data collection strategy that prioritizes validated secondary records complemented by targeted primary observations. The core of the research relies on internal PT XYZ and PLTU documentation including production realizations, demand forecasts through 2027, and historical stockpile utilization which provides a reliable, "officially reviewed" baseline for calculating safety stock and modeling expansion needs. To ensure these models reflect the most current operational realities, primary data is gathered through direct observation of equipment cycle times and real-time stockpile audits. This hybrid approach ensures that the resulting analysis is grounded in both long-term strategic planning (RKAP and RJPP) and "accurate, updated" field conditions, allowing for a precise evaluation of coal flow reliability and economic feasibility.

Data Analysis Method

This research utilizes a quantitative analytical framework to optimize coal flow and stockpile management at Pit ABC, transforming numerical data into strategic operational recommendations. The methodology is structured into three integrated stages: safety stock evaluation, capacity simulation, and economic validation. Initially, the study employs a variability-based inventory approach to calculate safety stock requirements through 2027, factoring in demand volatility, lead time fluctuations, and the critical service levels required for continuous power plant operations.

Following the inventory assessment, the research applies a cumulative flow balance model to simulate stockpile fluctuations based on 2024 historical dynamics and projected growth. This stage identifies the "optimal capacity" required to house both safety stock and flow buffers while eliminating the inefficiencies of overflow and "double handling." Finally, a cost-benefit analysis (CBA) bridges the gap between technical requirements and economic reality. This analysis converts structural needs into capital expenditures for excavation and construction, weighing them against the quantifiable benefits of enhanced equipment efficiency and the reduction of non-value-adding operational costs.

RESULTS AND DISCUSSION

Safety Stock Analysis

The transition from a fixed minimum safety stock of 100,000 tons to a variability based model reveals a looming structural deficit in PT XYZ's supply reliability. By applying the Peter L. King formulation, the study demonstrates that as coal throughput scales toward 2027, the required buffer must increase by over 71% to reach 171,194 tons/month to maintain a 95% service level. This surge is driven by the fact that higher demand volumes amplify the absolute impact of lead-time and consumption fluctuations, even when relative variability remains constant. Consequently, maintaining the legacy benchmark would leave the power plant with a 71,000-ton shortfall by 2027, covering only 58% of the necessary reserve and creating an intolerable risk for baseload operations. This widening gap proves that safety stock cannot remain a static policy but must be integrated into broader capacity planning to prevent the inefficiencies of temporary stockpiling and repeated handling.

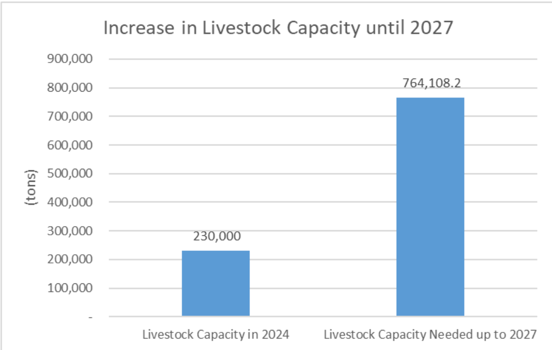
Table IV.1 Safety Stock Value

Year	LT (h)	S_{LT}(h)	D (t/h)	S_D(t/h)	Safety Stock (t/day)	Safety Stock (t/month)
2025	0.34	0.11	358.20	169.55	3,498.94	103,742.71
2026	0.34	0.11	549.07	240.69	5,022.15	150,664.59
2027	0.34	0.11	662.10	270.33	5,706.47	171,193.98

Livestock Capacity Analysis

The livestock capacity analysis reveals that the current 230,000 ton limit has shifted from a functional buffer into a structural bottleneck, necessitating a 5.55-fold expansion to approximately 832,118 tons by 2027. Based on daily cumulative flow simulations which peaked at an accumulation of 764,108 tons this expansion is required to accommodate projected production surges while simultaneously protecting the increased safety stock levels. Aligning physical infrastructure with these throughput dynamics allows the system to transition to a "direct flow" model, eliminating the systemic reliance on temporary stockpiles and the associated waste of double handling. Ultimately, this structural adjustment enables the stockpile to function as a true strategic buffer, absorbing variability and reducing operational costs as coal production and consumption scale toward 2027.

Figure IV.1 Increase in Livestock Capacity until 2027



Improvement Scenario

The proposed improvement strategy transforms the coal supply chain by synchronizing physical livestock expansion with a streamlined "direct flow" operational model. By executing a phased expansion scheduled for Q1 2026 and involving the excavation of 26,557 BCM the system provides the necessary structural capacity to accommodate increased safety stock without relying on temporary storage. This infrastructure growth facilitates a critical reconfiguration where coal is hauled directly from Pit ABC to the livestock, effectively eliminating the "non value adding waste" of double handling and reducing total hauling distances. Guided by lean management principles, this two pronged approach replaces reactive, high cost interventions with a continuous, predictable flow, ensuring long-term supply reliability and cost efficiency that can be sustained through rigorous performance monitoring of equipment hours and stockpile stability.

Cost and Benefit Analysis

The economic evaluation demonstrates that the livestock expansion project is an exceptionally high-yield investment, yielding an annual operational saving of approximately Rp 317.5 billion against a modest initial CAPEX of Rp 634.6 million. By increasing the stockpile capacity to accommodate 12-meter-high volumes, the system eliminates the "non-value-adding waste" of double handling and reduces the total hauling distance by 0.6 km per ton through a direct-flow model. This structural shift slashes the operational unit cost from Rp 38,190/ton/km to Rp 10,039/ton/km, ensuring that the project pays for itself within a fraction of its first year of operation. Ultimately, this Cost-Benefit Analysis confirms that aligning physical infrastructure with projected 2027 throughput not only mitigates the risk of power plant stockouts but also transforms a risk-prone, cost-intensive supply chain into a lean and highly profitable operation.

Aspect	Current Condition (TS Reliance)	Improved Condition (Expanded Livestock)
Hauling Logic	Indirect (Mine - TS - Livestock)	Direct (Mine - Livestock)
Total Distance	3.0 km	2.4 km (0.6 km reduction)
Cost Per Ton/Km	Rp 38,190	Rp 10,039
Primary Cost Driver	High recurring OPEX (Double Handling)	One-time CAPEX (Expansion)
Equipment Use	High (Corrective/Rehandling hours)	Optimized (Productive hours)

CONCLUSION AND RECOMMENDATION

Conclusion

The findings of this research confirm that PT XYZ’s current supply chain configuration is reaching its structural and economic limits. Quantitatively, the transition from a fixed to a variability-based inventory model shows that safety stock requirements must scale to 171,194 tons/month by 2027 to mitigate the risks of increased throughput, rendering the legacy 100,000 ton benchmark obsolete. To physically support this inventory and absorb flow fluctuations, a 5.55-fold expansion of the livestock capacity to 764,108 tons is essential to prevent the stockpile from becoming an operational bottleneck.

From an economic perspective, this expansion facilitates a "direct flow" model that eliminates the waste of double handling and reduces hauling distances by 0.6 km/ton, slashing unit costs to Rp 10,039/ton/km. With an annual saving of Rp 317.5 billion and a minimal initial investment, the improvement is not only a technical necessity for power plant reliability but also a highly profitable strategic shift toward long term operational sustainability.

Recommendation

To secure the long-term reliability of the coal supply chain, management should prioritize the expansion of livestock capacity to approximately 764,108 tons while transitioning to a "direct flow" model from Pit ABC to eliminate the systemic waste of double handling. This structural shift, paired with a move toward dynamic, variability-based safety stock policies, will replace the obsolete 100,000-ton benchmark and unlock nearly Rp 317.5 billion in annual operational savings. Furthermore, future research should bridge the gap between upstream improvements and downstream delivery by optimizing dump hopper and conveyor throughput, alongside the integration of First-In–First-Out (FIFO) principles to mitigate spontaneous combustion risks. By synchronizing physical infrastructure, lean flow configurations, and advanced quality monitoring, PT XYZ can ensure a resilient and cost-efficient energy supply through 2027 and beyond.

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