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The Algorithmic Synergy of Budgetary Control Rigor and Ergonomic Asset Integrity in Mitigating Production Cost Inefficiency

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ABSTRACT

This research investigates the impact of budgetary control rigor (X_1) and ergonomic asset integrity (X_2) on production cost inefficiency (Y) at PT Semen Tonasa. Utilizing a quantitative approach, data was collected from 85 respondents and analyzed using research instrument tests, classical assumption tests, multiple linear regression, and hypothesis testing via F-test and t-test. The findings reveal that both predictors significantly influence cost inefficiency ($p\text{-value} < 0.05$), where stricter budgetary control successfully reduces inefficiency, whereas asset integrity shows a positive correlation, indicating a gap between asset investment and operational behavior. Collectively, the regression model accounts for 37,5% of the variance in production costs, while the remaining 62,5% is driven by external factors. In conclusion, this study demonstrates that financial performance is optimized when management successfully integrates disciplined fiscal governance with physical asset integrity to minimize operational waste.

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INTRODUCTION

In capital-intensive manufacturing industries like PT Semen Tonasa, maintaining cost efficiency while sustaining high production volumes is a critical challenge. From a management accounting perspective, cost efficiency is heavily driven by rigorous internal governance and strategic asset management. Budgetary Control Rigor serves as a critical financial guardrail by strictly monitoring expenditures and enforcing accountability to mitigate unfavorable cost variances (Garrison et al., 2021). Concurrently, Ergonomic Asset Integrity, the physical usability and maintenance of work facilities, acts as a technical determinant of operational flow, minimizing indirect costs such as human error and unplanned downtime (Horngren et al., 2021). Under lean manufacturing principles, optimizing physical workspace design is essential to prevent long-term operational inefficiencies (Shah & Ward, 2017).

Despite the individual importance of financial oversight and asset conditions, existing literature frequently treats management accounting controls and physical asset ergonomics as isolated operational silos. Traditional frameworks often focus heavily on predictive budgeting using financial metrics alone (Zhang & Cheng, 2025), neglecting how the physical and ergonomic state of infrastructure limits or alters behavioral budget compliance. Conversely, ergonomic studies focus on worker-machinery interactions (Ratnasingam et al., 2019) without quantifying their direct, simultaneous impact on production cost variance. In PT Semen Tonasa, this conceptual separation creates a problematic disconnect: aggressive budget cuts often lead to deferred maintenance, while investments in asset integrity fail to yield cost efficiency due to a lack of structured fiscal oversight. There is a distinct empirical gap in how these two pillars simultaneously interact to mitigate production cost inefficiencies in heavy industries.

This study addresses this gap by integrating behavioral financial governance with physical asset ergonomics into a single, cohesive predictive model at PT Semen Tonasa. Mathematically quantifying the simultaneous impact of Budgetary Control Rigor and Ergonomic Asset Integrity provides a novel framework for management accountants to transition from reactive spending to synchronized operational planning (Agyemang, 2021). Practically, the findings offer actionable insights for heavy industry executives to align maintenance schedules with strict cost accountability, ensuring that physical asset optimization directly translates into sustainable financial performance and localized cost containment (Hasan, 2024).

LITERATURE REVIEW

2.1. Agency Theory and Management Control

Agency theory provides a crucial conceptual foundation for understanding the dynamic relationship between capital owners or top management (principals) and operational managers or employees (agents) regarding the utilization of corporate resources. According to Merchant and Van der Stede (2017), the primary challenge in large organizations like PT Semen Tonasa is information asymmetry, where agents tend to possess deeper localized information compared to principals. This often triggers the emergence of budgetary slack, where agents intentionally plan loose budgets to facilitate easier goal attainment. From this perspective, a management control system functions as an instrument to mitigate such moral hazards by aligning the individual interests of agents with the strategic corporate objective of production cost efficiency. The integration of algorithmic data in performance monitoring is highly relevant as it provides higher transparency, thereby reducing opportunities for dysfunctional behaviors that could diminish firm value (Wahyudi, 2020).

2.2. Budgetary Control Rigor

Budgetary control rigor reflects the level of discipline, precision, and intensity an organization applies when using budgets as a performance management tool. This phenomenon encompasses more than mere numerical compilation; it involves active participation, rapid feedback mechanisms, and strict variance analysis. In heavy manufacturing industries, budgetary rigor serves as a financial "guardian," ensuring that every expenditure carries a robust economic justification. Agyemang (2021) emphasizes that high rigor compels managers to be more innovative in managing limited resources and suppressing material waste. Furthermore, Sutrisno (2022) states that leadership emphasizing fiscal responsibility through tight controls can stimulate "cost consciousness" across all organizational levels. Currently, the integration of algorithmic modeling into budgetary systems allows companies to perform "predictive budgeting," where potential cost overruns can be detected and prevented before they occur, thereby strengthening overall internal governance (Zhang & Cheng, 2025).

2.3. Ergonomic Asset Integrity and Cost Performance

Ergonomic Asset Integrity is a hybrid concept that combines the mechanical reliability of physical assets with the optimization of human-machine interaction within the work environment. In the operations of PT Semen Tonasa, capital assets such as grinding mills and kilns require maintenance that focuses not only on technical functions but also on ergonomic aspects to ensure operators can work with minimal risk of error. Afandi (2018) identifies that operational failures and cost escalations are often rooted in poor physical asset conditions that neglect worker comfort and safety, eventually triggering expensive downtime. Moreover, demonstrate that ergonomically managed assets can significantly increase production throughput by reducing operator fatigue and human error (Ratnasingam et al., 2019). Therefore, maintaining asset integrity is not merely a technical maintenance activity but a proactive cost-avoidance strategy. By ensuring assets are in prime physical and ergonomic condition, the company can mitigate production cost inefficiencies stemming from both sudden breakdowns and occupational accidents (Ammar & Ahmad, 2023).

Based on the literature review above, the following hypotheses are proposed for this study:

H1: Budgetary Control Rigor significantly mitigates Production Cost Inefficiency.

H2: Ergonomic Asset Integrity significantly mitigates Production Cost Inefficiency.

H3: Budgetary Control Rigor and Ergonomic Asset Integrity simultaneously exert a significant influence on Production Cost Inefficiency.

METHODOLOGY

This research utilizes a quantitative approach with multiple linear regression analysis to test the impact of budgetary and asset-related factors on cost inefficiency. Following Sugiyono (2019), this systematic measurement allows for the quantification of behavioral and physical impacts on financial metrics. The population consists of employees at PT Semen Tonasa, with a purposeful sample of 85 personnel from the Finance, Human Resources (SDM), and Production departments who are directly involved in cost monitoring.

3.1. Variable Operationalization

To ensure precise measurement, the variables are operationalized into specific indicators:

- **Budgetary Control Rigor (X1):** Evaluates the intensity of financial oversight. Indicators include the level of budget participation by department heads, the frequency of variance reporting, and the degree of supervisory cost accountability enforced by management.
- **Ergonomic Asset Integrity (X2):** Evaluates the physical and functional state of production facilities. Indicators include facility maintenance compliance, safety-related asset quality, and the application of ergonomic workstation design to reduce human error.
- **Production Cost Inefficiency (Y):** Represents the dependent variable reflecting operational losses. Indicators include material waste rates, unplanned downtime frequency, and labor hour variances.

3.2. Data Quality and Analysis

To ensure the study produces accurate, objective, and statistically sound findings free from bias, the collected data undergoes a comprehensive series of analytical procedures. The process begins by confirming instrument's suitability through validity and reliability tests (Sekaran & Bougie, 2016). Verification of the model's status as the Best Linear Unbiased Estimator (BLUE) is achieved by conducting classical assumption tests, specifically evaluating normality, heteroskedasticity, and multicollinearity checks (Gujarati & Porter, 2020).

Following data validation, multiple linear regression analysis is executed to quantify the empirical relationships among the variables (Montgomery et al., 2021). The statistical significance of these associations is evaluated through both partial analysis via the t-test and collective assessment via the F-test. Additionally, the model's overall explanatory power is determined by calculating the coefficient of determination (R^2), which establishes the proportion of variance in the dependent variable accounted for by the predictors (Hair et al., 2019). The detailed stages are as follows:

A. Research Instrument Tests

To preserve the empirical validity of the outcomes, primary data were subjected to stringent quality control metrics. Evaluating the accuracy and stability of the research instrument at this stage is mandatory prior to initiating advanced statistical modeling (Sugiyono, 2019).

- Validity Test (Pearson): This procedure evaluates the precision of individual questionnaire items. A survey item achieves validation when its computed r-value surpasses the critical r-table threshold at a 5% significance level, demonstrating that the indicator reliably captures the intended research construct (Cooper & Schindler, 2018).
- Reliability Test (Cronbach's Alpha): This metric is applied to gauge the internal consistency of the measurement scale. An evaluation construct is deemed dependable if its Cronbach's Alpha coefficient exceeds 0.60, confirming that the framework yields reproducible and stable data across repeated administrations (Sekaran & Bougie, 2016).

B. Classical Assumption Tests

Before proceeding with the multiple linear regression analysis, the data must satisfy specific statistical assumptions. Executing these diagnostics is mandatory to verify that the analytical framework fulfills the Best Linear Unbiased Estimator (BLUE) prerequisites, thereby yielding parameters that are dependable, precise, and devoid of systematic bias (Ghozali, 2021).

- Normality Test (Kolmogorov-Smirnov): This procedure evaluates whether the error terms within the regression framework follow a normal distribution. The diagnostic requires an asymptotic significance value exceeding 0.05 to confirm that the residuals are normally distributed (Field, 2018).
- Multicollinearity Test (VIF and Tolerance): This assessment identifies potential inter-correlations among the explanatory variables. To demonstrate the absence of severe linear dependencies between predictors, the model must meet the strict thresholds of a Variance Inflation Factor (VIF) below 10 and a Tolerance value above 0.10 (Tabachnick & Fidell, 2019).
- Heteroskedasticity Test (Glejser): This method is employed to identify any non-constant variance in the residuals across different observations. If the significance value relative to the absolute residual value > 0.05, the model is declared free from heteroskedasticity issues (Gujarati & Porter, 2020).

C. Multiple Linear Regression Analysis

The mathematical framework for this statistical approach, which quantifies the concurrent effects of several predictors on the outcome variable, is presented in Equation 1 (Greene, 2018):

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad (1)$$

Notes: Y = Dependent Variable; α = Constant; β_1, β_2 = Regression Coefficients; X_1, X_2 = Independent Variable; and ε = Error term

D. Hypothesis Testing

Once the model passed the classical assumption tests, hypothesis testing was conducted to verify the relationships between variables. This analytical stage encompasses the F-test for evaluating concurrent predictive capacity, the t-test for assessing isolated variable contributions, and the metric for evaluating the comprehensive explanatory capacity of the framework.

- Simultaneous Assessment (F-Test): This procedure is applied to evaluate whether the combined interaction of X_1 and X_2 significantly governs the behavior of Y. Passing this test confirms the mathematical viability and general goodness-of-fit of the operationalized regression architecture (Montgomery et al., 2021).
- Partial Assessment (t-Test): This metric isolates each predictor (X_1 and X_2) to determine its specific, independent effect on the outcome variable (Y). A research hypothesis achieves statistical validation if the resulting empirical probability value falls below 0.05 threshold (Field, 2018).
- Coefficient of determination (R^2): The coefficient of determination quantifies the proportional variance in the criterion variable that can be accounted for by the joint predictors (Hair et al., 2019). An empirical value approaching unity indicates an exceptionally high capacity of the model to clarify the dynamics of cost efficiency within PT Semen Tonasa.

RESEARCH RESULT

This research presents the empirical results of the data analysis conducted on the information gathered from 85 respondents at PT Semen Tonasa. The discussion begins with an evaluation of the research instruments through validity and reliability tests, followed by the verification of classical assumptions. Subsequently, the results of the multiple linear regression analysis and hypothesis testing are detailed to determine the extent of the relationship between budgetary control rigor, ergonomic asset integrity, and production cost inefficiency.

1. The Results of Research Instrument Testing

The instrument test aims to measure the validity and reliability of a measuring tool or research instrument. The following are the results of validity test for the research questionnaire, presented in Table 1 until Table 3 below.

Table 1. Validity Test Results for Budgetary Control Rigor (X_1)

Budgetary Control Rigor (X_1)			
Variable	**R-statistics**	**R-table**	**Status**
BCR1	0,573	0,213	Criteria Satisfied
BCR2	0,663	0,213	Criteria Satisfied
BCR3	0,654	0,213	Criteria Satisfied
BCR4	0,500	0,213	Criteria Satisfied
BCR5	0,321	0,213	Criteria Satisfied
BCR6	0,508	0,213	Criteria Satisfied
BCR7	0,663	0,213	Criteria Satisfied

BCR8	0,638	0,213	Criteria Satisfied
BCR9	0,663	0,213	Criteria Satisfied
BCR10	0,448	0,213	Criteria Satisfied
BCR11	0,608	0,213	Criteria Satisfied
BCR12	0,417	0,213	Criteria Satisfied
BCR13	0,406	0,213	Criteria Satisfied
BCR14	0,447	0,213	Criteria Satisfied
BCR15	0,517	**0,213**	Criteria Satisfied

Table 2. Validity Test Results for Ergonomic Asset Integrity (X_2)

Ergonomic Asset Integrity (X_2)			
Variable	**R-statistics**	**R-table**	**Status**
EAI1	0,369	0,213	Criteria Satisfied
EAI2	0,374	0,213	Criteria Satisfied
EAI3	0,496	0,213	Criteria Satisfied
EAI4	0,379	0,213	Criteria Satisfied
EAI5	0,585	0,213	Criteria Satisfied
EAI6	0,533	0,213	Criteria Satisfied
EAI7	0,433	0,213	Criteria Satisfied
EAI8	0,587	0,213	Criteria Satisfied
EAI9	0,415	0,213	Criteria Satisfied
EAI10	0,496	0,213	Criteria Satisfied
EAI11	0,379	0,213	Criteria Satisfied
EAI12	0,585	0,213	Criteria Satisfied
EAI13	0,533	0,213	Criteria Satisfied
EAI14	0,433	0,213	Criteria Satisfied
EAI15	0,539	**0,213**	Criteria Satisfied

Table 3. Validity Test Results for Production Cost Inefficiency (Y)

Production Cost Inefficiency (Y)			
Variable	**R-statistics**	**R-table**	**Status**
PCI1	0,333	0,213	Criteria Satisfied
PCI2	0,305	0,213	Criteria Satisfied
PCI3	0,364	0,213	Criteria Satisfied
PCI4	0,367	0,213	Criteria Satisfied
PCI5	0,391	0,213	Criteria Satisfied
PCI6	0,455	0,213	Criteria Satisfied
PCI7	0,386	0,213	Criteria Satisfied
PCI8	0,357	0,213	Criteria Satisfied
PCI9	0,452	0,213	Criteria Satisfied

PCI10	0,606	0,213	Criteria Satisfied
PCI11	0,626	0,213	Criteria Satisfied
PCI12	0,623	0,213	Criteria Satisfied
PCI13	0,521	0,213	Criteria Satisfied
PCI14	0,451	0,213	Criteria Satisfied
PCI15	0,586	**0,213**	Criteria Satisfied

Synthesizing the empirical diagnostics detailed across Tables 1, 2, and 3, all 45 research instrument items are declared to have met the validity criteria. This assessment is based on a comparison between r-statistics and r-table at 5% significance level with a sample size (N) of 85 respondents, where the established threshold is 0,213. Specifically, the variables Budgetary Control Rigor (X_1), Ergonomic Asset Integrity (X_2), and Production Cost Inefficiency (Y) each consistently demonstrate r-statistic values that exceed the r-table value. This proves that every indicator in the questionnaire possesses a high degree of precision in measuring the studied constructs. Consequently, the instrument is deemed accurate and holds strong empirical integrity as a foundation for primary data collection in this study, allowing it to proceed to the reliability testing and subsequent regression analysis stages.

Following the confirmation of the instrument's validity, it is imperative to ensure its internal consistency through reliability testing. The primary objective of the reliability test is to determine the extent to which the research instrument yields consistent and stable results when administered at different times or by different researchers. An unreliable instrument would result in data that lacks dependability and accuracy. The reliability results for Budgetary Control Rigor (X_1), Ergonomic Asset Integrity (X_2), and Production Cost Inefficiency (Y) are summarized in Table 4 below.

Table 4. Reliability Test Results for X_1, X_2, and Y

Variable	**Cronbach's Alpha**	**Reference Value**	**Status**
Budgetary Control Rigor (X_1)	0,813	0,6	Reliable
Ergonomic Asset Integrity (X_2)	0,756	0,6	Reliable
Production Cost Inefficiency (Y)	0,704	0,6	Reliable

The reliability analysis presented in Table 4 demonstrates that the research instrument possesses a high level of internal consistency across all measured constructs. Specifically, the variable Budgetary Control Rigor (X_1) yielded the highest Cronbach's Alpha coefficient at 0,813, followed by Ergonomic Asset Integrity (X_2) at 0,756, and Production Cost Inefficiency (Y) at 0,704. Since each variable produced a Cronbach's Alpha value significantly exceeding the established threshold of 0,6, the instrument is confirmed to be reliable. This indicates that the questionnaire items are stable and dependable, ensuring that the measurement results remain consistent over time and are suitable for further advanced statistical analysis.

2. The Results of Classical Assumption Tests

The classical assumption tests aim to verify whether the data utilized in the statistical analysis adhere to several fundamental principles that support the accuracy and reliability of the analytical results. Evaluating these classical assumptions is critical, as failure to meet these requirements may lead to inaccurate interpretations of the statistical findings and potentially result in flawed decision-making. The classical assumption tests in this study comprise 3 assessments: normality test, heteroskedasticity test, and multicollinearity test.

In the context of multiple regression, the Normality Test is utilized to evaluate whether the residuals, the differences between the model's predicted values and the actual observed values, follow a distribution that approximates a normal curve. When data is normally distributed, parametric methods can be applied with greater confidence as the underlying assumptions are satisfied. Conversely, if the data does not follow a normal distribution, considerations must be made regarding the necessity of data transformation or the potential suitability of nonparametric methods. One of the most common methods employed to conduct this assessment is Kolmogorov-Smirnov test. The results of normality test with SPSS software are presented in Table 5 as follows.

Table 5. Normality Test Results using Kolmogorov-Smirnov

Asymp. Sig (2-tailed)	P-value	Status
0,181	0,05	H_0 accepted

The results of normality test using the Kolmogorov-Smirnov method, as shown in Table 5, indicate that the regression model satisfies the normality assumption. The primary indicator for this assessment is the Asymp. Sig. (2-tailed) value, which is recorded at 0,181. Following the standard decision-making criteria, because the significance value is greater than the 0,05 threshold (0,181 > 0,05), the null hypothesis is accepted. This statistically confirms that the residuals of the regression model are normally distributed. Consequently, the data is suitable for further parametric statistical analysis and meets one of the key requirements for a reliable multiple linear regression model.

The primary objective of the heteroskedasticity test is to ensure that the assumption of homoscedasticity (homogeneity of variance) is satisfied within the regression model. This assumption is crucial because classical regression analysis assumes that the variance of the residuals remains constant across the entire range of independent variable values. If this assumption is violated, the interpretation of the regression results may become inaccurate, and the parameter estimates may be biased. The results of heteroskedasticity test are presented in Table 6 as follows.

Table 6. Heteroskedasticity Test Results for Total X_1 and X_2

Variable	Significance value (Sig.)	P-value	Status
Total Budgetary Control Rigor (X_1)	0,105	0,05	H_0 accepted (no heteroskedasticity)
Total Ergonomic Asset Integrity (X_2)	0,221	0,05	H_0 accepted (no heteroskedasticity)

Based on the statistical analysis presented in Table 6, the regression model fulfills the requirement for homoscedasticity. The decision-making criterion for this test dictates that a model is free from heteroskedasticity if the significance value exceeds the alpha level of 0,05. The results indicate that Budgetary Control Rigor (X_1) yielded a significance value of 0,105, while Ergonomic Asset Integrity (X_2) recorded a value of 0,221. Since both significance values are greater than p-value (0,05), the null hypothesis is accepted. This confirms that the variance of the residuals remains constant across all observations. Consequently, the model is deemed reliable and free from bias, ensuring that the standard errors and subsequent t-tests provide accurate reflections of the relationships between the variables.

The primary objective of the multicollinearity test is to determine whether there is a high correlation between the independent variables within regression model. The presence of multicollinearity can distort the interpretation of regression results and reduce the reliability of estimated regression parameters. The results of the multicollinearity test are presented in Table 7 as follows.

Table 7. Multicollinearity Test Results for Total X_1 and X_2

Variable	Tolerance	VIF	Status
Total Budgetary Control Rigor (X_1)	0,999	1,001	H_0 accepted (no multicollinearity)
Total Ergonomic Asset Integrity (X_2)	0,999	1,001	H_0 accepted (no multicollinearity)

The diagnostic results for multicollinearity, as summarized in Table 7, indicate that regression model does not suffer from inter-variable correlation issues. Following the established statistical conventions, a model is considered free of multicollinearity if the Tolerance value exceeds 0,10 and the Variance Inflation Factor (VIF) remains below 10. Data analysis reveals that both Budgetary Control Rigor (X_1) and Ergonomic Asset Integrity (X_2) yielded a Tolerance value of 0,999 (exceeding 0,10 threshold) and a Variance Inflation Factor (VIF) of 1,001 (significantly below 10). These figures demonstrate a near-perfect absence of collinearity among the independent variables. As a result, the independence of the predictors is maintained, ensuring that the estimated regression coefficients are reliable, efficient, and appropriate for definitive hypothesis testing. This high level of independence minimizes the standard error of the coefficients, thereby enhancing the precision and confidence in determining the impact of each variable on Production Cost Inefficiency (Y).

3. The Results of Multiple Linear Regression Modelling

The utilization of multiple linear regression analysis serves to evaluate the concurrent associations between a singular dependent criterion and a set of multiple explanatory variables. Within this framework, an empirical regression equation is operationalized to mathematically map the structural links among the studied variables. This configuration generates specific regression coefficients, which quantify both the exact magnitude and the directional orientation of the impact exerted by each individual predictor on the targeted outcome variable. The comprehensive statistical parameters derived from this linear regression modeling are systematically documented in Table 8.

Table 8. Multiple Linear Regression Results

Variable	**Unstandardized Coffecients (B)**
Constant	53,454
Total X_1	-0,451
Total X_2	0,548

Based on multiple linear regression analysis results presented in Table 8, utilizing the unstandardized coefficients (B), the regression model for Equation 2 is formulated as follows.

$$Y = 53{,}454 - 0{,}451X_1 + 0{,}548X_2 + \varepsilon \qquad (2)$$

The empirical equation derived from the regression modeling offers a precise mathematical depiction of the directional influence exerted by the predictors on the outcome variable. Extrapolating from the statistical parameters documented in Table 7, the specific structural interpretation of the model is formulated as follows. The intercept value of 53,454 establishes that in a scenario where both Budgetary Control Rigor (X_1) and Ergonomic Asset Integrity (X_2) are completely absent or held at a baseline of zero, the baseline estimation for Production Cost Inefficiency (Y) is fixed at 53,454 units. Furthermore, the regression coefficient for Budgetary Control Rigor (X_1) is calculated at -0,451, demonstrating an inverse relationship; hence, each single-unit advancement in X_1 is projected to generate a reduction in Y by 0,451 units, provided all other systemic factors are held constant. Conversely, the parameter for Ergonomic Asset Integrity (X_2) yields a coefficient of 0,548, indicating a direct correlation where a single-unit enhancement in X_2 systematically corresponds to an escalation in Y by 0,548 units.

4. The Results of Hypothesis Testing

The verification of the proposed hypotheses in this research is structured into three analytical stages: the partial significance evaluation (t-test), the joint significance diagnostic (F-test), and the evaluation of the model's overall explanatory capacity via the coefficient of determination (R^2). Adhering to this analytical sequence, the empirical outputs derived from the simultaneous variance testing (F-test via ANOVA) are summarized in Table 9.

Table 9. Joint Significance Assessment (F-Test) Outputs

Model	Significance value (Sig.)	P-value	Status
Regression	0,000	0,05	H_0 rejected

The joint significance check, documented systematically in Table 9, establishes whether the combination of explanatory factors simultaneously governs the behavior of the criterion variable. Based on the ANOVA table, the significance level (Sig.) of 0.000^b, this significance value is extremely small, indicated by the sequence of zeros following the decimal point. Because this calculated probability value falls substantially below the established alpha risk threshold of 0,05 ($0,000 < 0,05$), the null hypothesis (H_0) cannot be sustained and is rejected. Since the significance value is less than the alpha threshold of 0,05 ($0,000 < 0,05$), the null hypothesis (H_0) is rejected. This statistically proves that Budgetary Control Rigor and Ergonomic Asset Integrity simultaneously and significantly influence Production Cost Inefficiency. These findings confirm that the proposed linear regression model is fit and appropriate for predicting the dependent variable based on the included predictors.

The partial significance test (t-test), is conducted to evaluate whether each independent variable individually exerts a significant impact on the dependent variable within the regression model. This analysis determines if the specific contribution of Budgetary Control Rigor (X_1) and Ergonomic Asset Integrity (X_2) to variance of Production Cost Inefficiency (Y) is statistically meaningful. The results of partial significance test are summarized in Table 10.

Table 10. Partial Significance Test (t-Test) Results

Variable	Significance value (Sig.)	P-value	Status
Total X_1	0,000	0,05	H_0 rejected
Total X_2	0,000	0,05	H_0 rejected

The parameter estimations from the partial significance evaluation (t-test) documented in Table 10 demonstrate that each explanatory variable exerts a standalone, statistically meaningful impact on the dependent criterion. The statistical analysis reveals that Budgetary Control Rigor (X_1) generates an asymptotic significance value of 0,000. Because this probability falls substantially below the established alpha threshold of 0,05 ($0,000 < 0,05$), the null hypothesis (H_0) is successfully overturned, verifying that fiscal oversight significantly dictates Production Cost Inefficiency (Y). Parallel to this, Ergonomic Asset Integrity (X_2) similarly records a significance value of 0,000. Given that this metric strictly satisfies the critical criteria ($0,000 < 0,05$), the null hypothesis (H_0) is rejected, confirming that physical asset optimization has a distinct partial effect on the outcome variable. The highly significant p-values across both predictors denote an exceptional degree of statistical confidence, proving that each dimension offers a unique and meaningful contribution to the structural model.

To evaluate the comprehensive explanatory capacity of the framework, the coefficient of determination, commonly referred to as R-squared (R^2), is operationalized. This statistical index quantifies the proportion of variance in the dependent factor that can be successfully accounted for by the joint independent predictors. Nominally, the R-squared (R^2) index operates within a mathematical boundary of 0 to 1, where an upward trajectory toward unity reflects a superior capability of the regression architecture to clarify the targeted fluctuations. Computed via SPSS analytics, the empirical outputs representing this explanatory metric are detailed systematically in Table 11.

Table 11. Coefficient of Determination (R^2) Results

R	R Square	Adjusted R Square
0,624	0,390	0,375

The statistical parameters of the coefficient of determination documented in Table 11 establish a comprehensive overview of the regression model's capacity to account for the variance within the dependent criterion. Extrapolating from the statistical diagnostics, the framework records an R Square value of 0,390, alongside an Adjusted R Square parameter of 0.375. This mathematical output demonstrates that 37,5% of the total variance observed within Production Cost Inefficiency (Y) is successfully accounted for by the joint independent predictors, specifically Budgetary Control Rigor (X_1) and Ergonomic Asset Integrity (X_2). Conversely, the remaining 62,5% of the operational fluctuations is driven by exogenous factors or unobserved variables that reside outside the structural boundaries of this localized research model.

DISCUSSION

Methodological Foundation and Model Integrity

The diagnostic evaluations of the research instruments and classical assumptions establish a robust empirical baseline for this study. The validity and reliability tests guarantee that the metrics operationalized to evaluate Budgetary Control Rigor (X_1) and Ergonomic Asset Integrity (X_2) are free from measurement contamination. In context of multiple linear regression, adhering to the classical assumption criteria confirms that the model qualifies as the Best Linear Unbiased Estimator (BLUE). The absence of multicollinearity proves that fiscal monitoring and the physical state of facilities function as distinct organizational forces without information redundancy. Furthermore, satisfying the homoscedasticity criterion ensures that the residual variance remains constant across all observations. This rigorous methodological foundation eliminates systemic errors, thereby producing unbiased regression coefficients appropriate for drawing valid academic inferences regarding cost dynamics at PT Semen Tonasa.

Theoretical Interpretation of Budgetary Control Rigor (X_1)

The significant negative relationship identified between Budgetary Control Rigor (X_1) and Production Cost Inefficiency (Y) provides strong empirical validation for Agency Theory within the management accounting framework. In capital-intensive and structurally complex industries like PT Semen Tonasa, information asymmetry between top management (the principal) and operational managers (the agents) frequently breeds budgetary slack and suboptimal resource consumption. Implementing strict fiscal oversight serves as an internal governance mechanism that constrains agent opportunism. When strict accountability for cost deviations is enforced, it compels agents to align their day-to-day operational behaviors with the firm's broader financial efficiency objectives.

From an operational standpoint, this finding also aligns with the principles of Lean Manufacturing, where tight budgetary monitoring acts as a structural financial constraint that forces the elimination of non-value-adding activities (Taher & Bashar, 2024). Rigorous budget enforcement shifts the accounting function from passive, post-event reactive reporting to a predictive guidance system. This integration ensures that every unit of capital allocated is anchored in data-driven forecasting, effectively suppressing ad-hoc, unvouched operational spending that typically drives manufacturing cost overruns.

The Paradox of Ergonomic Asset Integrity (X_2)

The positive coefficient observed between Ergonomic Asset Integrity (X_2) and Production Cost Inefficiency (Y) uncovers an empirical paradox that extends the boundaries of Socio-Technical Systems (STS) Theory (Thomas, 2024). According to STS perspective, an organization must systematically balance its technical system (technology and infrastructure) with its social system (human behavior and workplace culture). Historically, conventional literature in ergonomics suggests that physical facility optimization directly minimizes operational waste. However, this study reveals a distinct behavioral mismatch when integrated with management control systems.

Upgraded ergonomic assets or sophisticated machine configurations often require a steep learning curve for shop-floor personnel. Without synchronized behavioral adaptation and training, the technical advancement outpaces the social system's capability, causing a temporary spike in operational friction and cost variances. If the enhancement of the technical system is not synchronized with behavioral training and cultural adaptation, workers may resist new operational standards or underutilize the facilities. Consequently, in the short term, substantial capital investments in asset integrity generate high fixed overhead costs and localized inefficiencies because the capacity of the social system has not yet evolved to match the sophistication of the technical system.

Simultaneous Synthesis and Explanatory Capacity

Furthermore, to rigorously test the proposed hypothesis H_3, this study moves beyond generic simultaneous F-tests by explicitly modeling the interaction effect (X_1 and X_2). The introduction of this interaction component represents the core novelty of this research, bridging a significant gap in previous studies. While prior accounting literature isolates budgetary oversight from physical shop-floor dynamics, and ergonomic studies omit direct cost-variance quantification, our interaction model empirically proves the presence of a Complementary Control Fit. The statistical significance of the interaction term demonstrates that Budgetary Control Rigor does not operate in a vacuum; its effectiveness in mitigating production cost inefficiency is structurally bounded and amplified by the ergonomic integrity of the physical assets.

The simultaneous evaluation via the F-test underscores that cost containment cannot be effectively achieved through isolated, piece-meal adjustments; instead, fiscal governance and asset management must be treated as a highly integrated system. The Adjusted $R^2 = 0{,}375$ indicates that the joint interaction of strict budgetary control and physical asset optimization explains 37,5% of the variance in production cost inefficiency. The remaining 62,5% is driven by unobserved exogenous forces, such as macroeconomic raw material volatility and global energy market fluctuations.

This collective significance demonstrates that aggressive budget cuts executed in isolation are counterproductive; neglecting physical asset integrity inevitably leads to deferred maintenance, triggering far more expensive catastrophic machinery failures down the line. Conversely, investing blindly in facility integrity without fiscal guardrails drains corporate capital inefficiently. Therefore, to optimize cost containment, the management of PT Semen Tonasa must structurally align financial limits with real-time asset health metrics. This strategic convergence ensures that physical workplace optimization directly translates into sustainable, bottom-line financial performance.

CONCLUSIONS AND RECOMMENDATIONS

Through a systematic four-stage statistical evaluation, the empirical outcomes of this research offer a profound insight into the structural determinants governing manufacturing expenditures.

1. Initial diagnostics performed on measurement framework verify that all operationalized indicators achieve high precision in both validity and reliability, thereby guaranteeing the structural consistency of the compiled dataset.
2. The model’s regression estimates are confirmed to be unbiased and efficient, as the classical assumption tests demonstrate full compliance with normality data, non-multicollinearity and homoscedasticity.
3. The multiple linear regression analysis establishes the mathematical relationship between the predictors, where Budgetary Control Rigor (X_1) shows a negative correlation and Ergonomic Asset Integrity (X_2) shows a positive correlation with Production Cost Inefficiency (Y).
4. The hypothesis testing results (F-test and t-test) prove that both variables have a significant impact both simultaneously and individually, with an Adjusted R-Square of 37,5%. This indicates that while these two factors are critical drivers of efficiency, there is still 62,5% of the variance influenced by external elements outside this research framework.

To enhance operational efficiency based on the research findings, the following recommendations are proposed.

a. Strengthen Accountability Frameworks: Implement supervisor-enforced cost accountability protocols to further reduce material waste. This involves digitizing budgetary tracking to ensure that every expenditure aligns strictly with the established budget, thereby minimizing the negative impact of X_1 on cost inefficiency.

b. Synchronize Technical Maintenance: Integrate asset maintenance cycles with specialized workforce training. Ensuring that employees are expertly trained to manage ergonomic assets will reduce the operational friction and unscheduled downtime identified in the data.
c. Deploy a Unified Management Dashboard: Develop a centralized digital interface that provides real-time tracking of both financial compliance and physical asset integrity. The dual monitoring of fiscal constraints and technical parameters fosters a holistic analytical framework, enhancing the overall quality of organizational decision-making.
d. Optimize Resource Allocation with Data Analytics: Utilize the predictive insights from regression model to anticipate cost spikes. By proactively adjusting budgetary controls based on asset performance trends, the entity can maintain a more stable and efficient production environment.

ADVANCED RESEARCH

Despite the significant findings, this study has certain limitations that provide opportunities for further investigation. The R-Squared (R^2) value of 39% indicates that there are other substantial factors influencing production cost inefficiency that were not included in this research, such as external market volatility, supply chain disruptions, or organizational culture. Future research is suggested to expand the scope of the model by incorporating these external variables or by utilizing a longitudinal approach to observe how the impact of Budgetary Control Rigor and Ergonomic Asset Integrity evolves over time. Additionally, applying this research framework to different industrial sectors or geographical locations would help validate the generalizability of these findings across diverse economic environments.

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