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Research Article

# Technical Evaluation and Financial Analysis of a Retrofitting Investment Project for Production Machinery in a Cement Plant

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## ABSTRACT

In today's rapidly evolving industrial landscape, businesses are increasingly challenged to strike a balance between enhancing productivity and maintaining product quality. Company X, a renowned cement manufacturer in Indonesia, relies heavily on four key raw materials, among which clay is particularly crucial for the raw mix. Recent trends have shown a decrease in the Al2O3 composition of clay, necessitating adjustments in clay capacity to uphold quality standards. A thorough technical evaluation of the plant highlighted that a significant number of critical machines, totaling 17, were operating with mechanical availability below the desired threshold. Additionally, a utility analysis pinpointed a shortfall in meeting the required clay tonnage, leading to the identification of machines that would benefit from retrofitting. The financial implications of this initiative were substantial, with the initial investment for the upgrades and subsequent operational costs in the first year being considerable. Yet, this expenditure was offset by a notable profit in the first year post-retrofitting. Key financial metrics further underscored the project's viability: a highly favorable Net Present Value (NPV), an impressive Internal Rate of Return (IRR), a rapid Payback Period (PP), and a significant Profitability Index (PI). These parameters, derived from an exhaustive analysis, clearly support the strategic decision to invest in retrofitting the production machinery at Company X's cement plant, illustrating the project's feasibility and the prospective benefits of this investment.

**Keywords:** technical evaluation, financial analysis, retrofitting, investment project

## INTRODUCTION

In today's dynamic global market, the manufacturing industry, particularly cement manufacturing industry, is facing increasing competition and rapidly evolving challenges. Innovative strategies are essential to remain competitive. This industry, which is important for the global economy, serves as the basis of the construction sector, which is crucial for urban development and infrastructure expansion. The impact of this industry goes beyond its significant contribution to national economic growth; It also plays a crucial role in promoting employment, thereby supporting the livelihoods of millions of people. As the company navigates changing market demands and continued technological advancements, its adaptability becomes key to maintaining its critical role in global development.

Cement production, an essential element in construction, reflects the rate of development and urbanization, often acting as an indicator of a region's economic health and progress [1], [2]. Despite its significance, the industry confronts several critical challenges, such as the imperative for technological upgrades and rising operational costs. The success is contingent on optimizing production processes to enhance effectiveness and efficiency, coupled with the assurance of product quality. Crucial to achieving this optimization is the meticulous maintenance and upgrading of production machinery, along with the strategic selection of quality raw materials. These measures are vital for fulfilling production capacity while simultaneously adhering to industry standards, thus addressing the dual objectives of production efficiency and quality compliance. Studies have shown that strategic adaptations in these areas significantly impact a market position and sustainability [3]-[5], with a direct correlation between production practices and product standards [6], [7].

The production machinery, encompassing a wide range of equipment from raw material handling to final product packaging, serves as the backbone of cement production. It includes crushers for size reduction of raw materials, grinders for fine powdering, rotary kilns for clinker production, and ball mills for cement grinding [8], [9]. Each of these components plays a vital role in ensuring the efficiency, quality, and environmental sustainability of the production process. Given the energy-intensive nature of cement manufacturing, advancements in machinery technology directly impact the industry's economic viability [10]. In this regard, our research focuses into the practical aspects of retrofitting production machinery in cement plants.

Retrofitting, a strategic approach within the industrial sector, involves updating and enhancing existing systems and machinery by incorporating new technology or features, rather than completely replacing them. This approach has become increasingly popular across various industries, such as manufacturing, energy, and construction, in response to the dual pressures of evolving technological advancements and growing environmental concerns [11]. The impetus for retrofitting primarily arises from a need to boost efficiency, decrease energy consumption, comply with environmental regulations, and stay agile in the face of shifting market demands. The appeal of retrofitting lies in its ability to extend the lifecycle of equipment, maximize resource utilization, and foster sustainability [12]. Consequently, this approach leads to substantial cost savings, both in operational expenses and capital expenditure, by obviating the need for comprehensive overhauls of existing production lines.

The academic interest in this field is rapidly growing, as researchers delve into the multifaceted impacts of retrofitting, exploring its potential to revolutionize traditional manufacturing processes, enhance energy efficiency, and contribute to a more sustainable industrial future. The body of research surrounding the implementation of retrofitting across various industrial sectors provides insightful revelations about the transformative impact of this practice. Smith and Johnson [13] illustrates the critical role of retrofitting in coal-fired power plants. Their work emphasizes not just operational efficiency but also the substantial reduction in greenhouse gas emissions, aligning industrial practices with environmental sustainability goals. Lee [14] presents another compelling case where retrofitting older buildings leads to marked improvements in energy efficiency. This not only aligns with global sustainability targets but also underscores the cost-effectiveness of such endeavors. Patel [15] investigates the challenges and opportunities in retrofitting for electric vehicle production. This transition is pivotal for traditional manufacturers aiming to keep pace with evolving market demands for greener transportation options. Green [16] highlights retrofitting as a key to enhancing safety measures and process efficiency. This not only improves production metrics but also significantly uplifts the industry's safety standards. Kim and Nguyen [17] demonstrates how retrofitting can drastically reduce environmental impacts. Their research into water-saving and energy-efficient technologies showcases how the industry can achieve sustainability without compromising on productivity. Cavalett et al. [18] highlighted the large climate change mitigation potential achievable in the cement sector through the implementation of oxyfuel CCS and biomass use as alternative fuel. Collectively, these studies underscore a paradigm shift in various industrial sectors towards more sustainable and efficient practices through technological upgrades. Retrofitting emerges not just as a solution to modernize operations but also as a strategy to enhance environmental compatibility and economic viability.

In our study, retrofitting approach is addressed distinctively compared to previous research. We concentrate our investigative efforts specifically designed to boost productivity [19],[20], addressing retrofitting issue at cement manufacturing company in Indonesia (Company X). In response to the evolving challenges outlined in the industry, Company X exemplifies a proactive approach to maintaining competitive advantage. This company adopts a proactive strategy in managing its primary raw materials – limestone, silica stone, clay, and iron sand – essential for its five plants (Plant I–V). The quality of these materials, particularly clay, is vital due to its significant influence on the quality of raw mix which serving as the base material that undergoes a chemical transformation to form cement clinker. Key components like Al2O3 and H2O in clay are critical for maintaining the desired chemical composition of cement, as indicated by the industry standards [21]-[23].

Given the current industry dynamics, Company X are compelled to balance efficiency with quality assurance [24],[25]. Our examination of Company X's operations, including interviews with the Planning and Maintenance

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Evaluation department, highlighted the grinding process in the raw mill as a critical stage, where the blending of these materials determines the final product quality. A concerning trend has been observed at Company X – the Al2O3 levels in clay have been decreasing, often falling below the minimum requirement of 27%. This decline has prompted a comprehensive assessment by the Planning and Production Evaluation Unit, focusing on the availability and quality of clay in supply sources located in West Sumatra, Indonesia [see Appendix A.1 for the details]. Addressing the challenges with clay quality at Company X, our analysis reveals a critical resource constraint: the company's high-grade clay reserves, utilized at a rate of 1,000,000 tons annually, are estimated to be depleted within three years. On the other hand, low-grade clay, found in abundance in West Sumatra Province, boasts a substantial reserve of around 25 million tons. However, this shift to low-grade clay, which typically contains 18% Al2O3, necessitates an increase in the volume used to maintain the necessary chemical balance in the cement mix. This adaptation in the production process underscores the urgency of managing raw material quality and availability to ensure consistent cement quality standards.

In the context of Company X's adaptation to changing raw material quality, Plant IV emerges as a critical case study. This plant, a major production facility since 1993 with a capacity of 1,920,000 tons/year, has encountered significant challenges due to the shift in clay quality. Notably, the existing machinery at Plant IV, originally designed for higher-grade clay, now struggles to accommodate the lower Al2O3 content of the currently available clay. This discrepancy has led to a pressing need for retrofitting and upgrading the plant's machinery to handle the increased volume of low-grade clay efficiently, thereby maintaining the plant's production capacity. The situation at Plant IV exemplifies the broader impact of raw material quality changes on production processes in the cement industry, highlighting the necessity of continuous adaptation and technological upgrading. Detailed information on the current machinery capacity at Plant IV is outlined in Appendix A.2.

Clay is a vital material in cement production, playing a crucial role in the quality and efficiency of the end product [26],[28]. At Company X, this importance is reflected in the well-established clay storage and transport equipment present in each plant. However, as the company ramps up its operations, a significant challenge has emerged: the degradation of clay quality linked to increased usage. This escalation in clay usage not only strains the existing machinery but also necessitates a thorough assessment to identify equipment that falls short in capacity and requires retrofitting. To determine which machines need the retrofitting, a detailed review of the production process flow involving clay is essential. This process will involve evaluating each piece of equipment that handles clay, assessing its capacity and compatibility with the current volume of clay used. Such a methodical approach ensures that all machinery is optimally aligned with the increased demands of clay processing.

The necessity for retrofitting becomes apparent when analyzing the limitations of Plant IV's existing machinery. The current equipment is not adept at managing the lower Al2O3 content found in the available clay. This inadequacy in capability has been underscored by the Planning and Production Evaluation Unit, which has identified a notable lack of crucial hopper and feeder installations for effective clay processing. Addressing this gap through retrofitting is imperative for Plant IV to sustain its production efficiency and adhere to quality standards amidst changing raw material conditions. This strategy is in line with the primary goal of our study, which seeks to identify and implement efficient solutions for adapting to variations in raw material quality, thereby ensuring the ongoing sustainability of Company X's production processes.

Our exploration of the technical and financial dimensions of retrofitting at Company X's Plant IV necessitates a clear understanding of the current advancements in this area. The technical readiness and availability of relevant technology are crucial in evaluating the feasibility and impact of such retrofitting endeavors [29],[30]. Similarly, a comprehensive financial analysis is vital, covering aspects like investment requirements, operating expenses, revenue forecasts, financing sources, and profitability [31]-[33]. This study aims to build upon the existing knowledge by conducting an in-depth technical and financial examination of the retrofitting project at Plant IV, an essential undertaking in light of the changing clay quality and its consequent effects on the production process.

Our focus will be on determining the specific needs for retrofitting, such as identifying the capacity shortfalls in machinery at Plant IV due to the decreased Al2O3 levels in clay. This assessment is vital for ensuring that the retrofitting aligns with the current material conditions and the plant's production targets. Additionally, the financial viability of this retrofitting, including cost-benefit analysis and investment returns, will be scrutinized, using parameters like Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), Profitability Index (PI), and Benefit-Cost Ratio.

By integrating the technical and financial aspects, this study aims to offer a comprehensive understanding of the retrofitting process in the context of changing raw material quality in cement production. This approach is particularly relevant for Company X's Plant IV, where the degradation in clay quality necessitates a detailed evaluation of machinery and financial implications. In doing so, the research addresses a critical gap in the existing literature and proposes a novel approach to enhancing productivity through sustainable retrofitting, adapting to the evolving technological and material landscape in the cement manufacturing industry.

## METHODS

In this study, we took three steps to ensure thorough and accurate findings. Firstly, we collected data from various sources, including eligibility criteria for clay, production rates, step-by-step production processes, raw material consumption historical data, maintenance historical data, output historical data, and initial funding estimation for retrofitting investment. This data formed the basis for all further analyses.

The second step involved technical analysis, which was critical in determining the required production rate. We considered the quality level of clay processed in the past and future quality requirements to predict the necessary production rate. Using a series of equations, including (1), (2), and others, we determined the resulting production rate and predicted the required capacity of each piece of equipment involved. Any equipment with a capacity less than the requirement was considered for retrofitting, while equipment with sufficient capacity had its depreciation rate and reliability estimated for future usage.

In the final step, we carried out an in-depth financial analysis to guide the investment planning for retrofitting the identified equipment. This involved the application of various financial techniques, encompassing present worth, internal rate of return, pay-back period, benefit-cost ratio, and profitability index analyses. These methods were instrumental in providing a comprehensive financial perspective on the retrofitting investments, ensuring a thorough and informed decision-making process. To assess the feasibility of investing in each piece of equipment, we employed financial analysis tools, including Net Present Value (NPV), Internal Rate of Return (IRR), among others. This analytical approach enabled us to make informed decisions: where an investment was deemed feasible, retrofitting

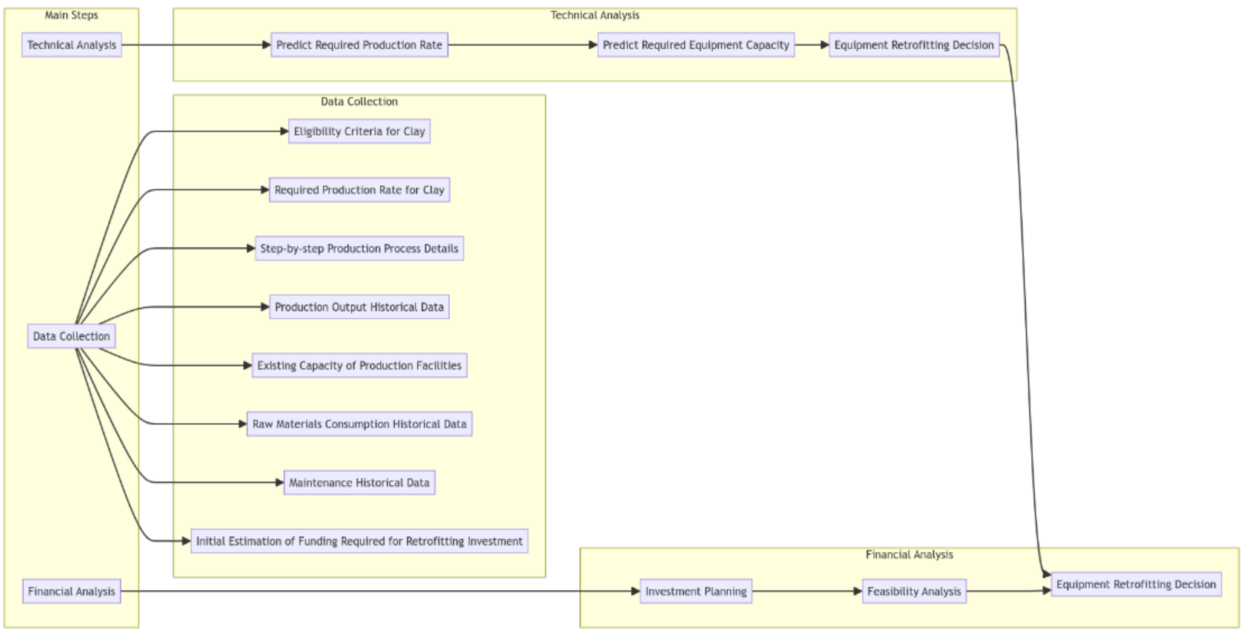


Figure 1. A Systematic Step by Step Process Analysis


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was recommended; alternatively, if it was not viable, procurement was suggested. Figure 1 illustrates the systematic process we followed in conducting these analyses, outlining each step in our evaluative methodology.

1. Flow-sheet System Analysis
   The Flow-sheet System Analysis at Plant IV is centered on an in-depth review of the production process flow-sheet. This analysis compares the quantity of clay required, utilizing interpolated data from historical and current clay quality benchmarks.

$$\text{Clay requirement for the following year} = \frac{\%\ \text{Al2O3 in clay in the preeding year} \times \text{Clay consumption in the current year}}{\%\ \text{Al2O3 projected for the following year}} \quad (1)$$

2. Evaluation of Flow-sheet and Capacity Analysis:
   This involves a detailed assessment of the production flow-sheet, from storage to the Raw Mill, along with a review of each machine's capacity to ensure it meets the current needs for clay usage.

$$\text{Mechanical Availability} = \frac{\text{Operating time}}{\text{Operating time} + \text{Breakdown time}} \times 100\% \quad (2)$$

$$\text{Utility shortage} = \frac{\text{Machine capacity} \times \text{Yearly operating time}}{\text{Projected clay requirement for the following year}} \times 100\% \quad (3)$$

3. Opportunity Loss Calculation:
   This process involves quantifying the opportunity loss in time at Raw Mill Plant IV. It is achieved by analyzing the daily report breakdowns, specifically focusing on disturbances attributed to capacity shortages. These time-based losses are then converted into tons, utilizing the detailed recapitulation data of the production's raw mix output per hour and month.

$$\text{Mechanical Availability (in ton)} = \text{Total breakdown time} \times \text{Production capacity} \quad (4)$$

4. Financial Analysis:
   This involves a thorough financial evaluation for retrofitting machinery, encompassing cost planning, cash flow projection, and a feasibility study based on various financial metrics. Key aspects include:
   a. Opportunity of Cement Loss: This entails estimating the potential financial impact caused by shortages in cement supply.
   b. Profit/Loss Calculation: This process involves calculating profits and losses by taking into account income, operational expenses, maintenance costs, and asset depreciation.
   c. Net Present Value (NPV): A method for a quantitative assessment of a project's feasibility, considering the time value of money.
   d. Internal Rate of Return (IRR): A technique to evaluate the project's profitability by comparing it with the Minimum Attractive Rate of Return (MARR).
   e. Payback Period: An analysis to determine the duration required to recoup the initial investment in the project.
   f. Profitability Index: A measure used to assess the profitability of a project in relation to the investment made.

5. Feasibility Assessment:
   This process involves a comprehensive evaluation of a project's feasibility by thoroughly analyzing key financial indicators. These include Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Profitability Index, and the Benefit-Cost Ratio. Each parameter is meticulously assessed to determine the overall viability and potential success of the project.

## RESULTS AND DISCUSSION

The investment project at Plant IV of Company X, aimed at retrofitting production machinery, underwent a detailed technical evaluation conducted in two distinct stages. Initially, the focus was on analyzing the tonnage requirements

Table 1. Effect of Abnormal Value of Quality Parameters on Raw Mix

| Quality Parameters | Value | Impact |
|---|---|---|
| Lime Saturation Factor (LSF) | > 100 | Causing higher freedom CaO, need more energy to burning |
| | < 100 | Causing lower freedom CaO, liquid phase and coating |
| Silica Modulus (SIM) | > 2.50 | Increasing heat needs to burn clinker |
| | < 2.35 | Reduce cement setting time |
| Alumina Modulus (ALM) | > 1.50 | Reduce SIM value |
| | < 1.40 | Lowering the compressive strength of cement |

of clay, particularly considering the Al2O3 content in the currently used low-grade clay. This analysis was crucial in understanding the material's impact on the production process. The subsequent stage of the evaluation shifted to a closer examination of the machinery at Plant IV, specifically those machines directly involved in handling and processing clay materials.

Ensuring the quality of the clay material used in production hinges on meeting specific Al2O3 and H2O level specifications. A drop in the quality of clay can adversely affect the quality of the Raw Mix, thereby influencing the attainment of essential quality parameters, including the Lime Saturation Factor (LSF), Silica Modulus (SIM), and Alumina Modulus (ALM). Crucial to these parameters are the key components: SiO2, which is derived from Silica Stone, Al2O3 from the Clay, and Fe2O3 from Iron Sand. Each of these elements plays a pivotal role in maintaining and achieving the desired quality standards in the production process.

The LSF is paramount among the quality standards, requiring a precise target value of 100, which is achieved through a meticulous balance of Silica Stone, Clay, and Iron Sand capacities. Not meeting these stringent quality parameters can lead to significant cascading effects on the Raw mix quality, as detailed in Table 1. The precise calibration of these materials is crucial for maintaining production efficiency and product quality.

Company X has proactively established a standard threshold for the Al2O3 content in clay, mandating a minimum of 27%. Despite this measure, there has been a continual decrease in Al2O3 levels, consequently increasing the demand for clay, a trend clearly depicted in Table 2. In anticipation of a further decline in clay quality, it has become imperative to adjust the capacity of the production machinery at Plant IV. This adjustment is crucial to ensure that the machinery remains efficient and effective until future conditions warrant a subsequent readjustment, thereby aligning the production capabilities with evolving material quality.

In preparation for a scenario where the Al2O3 content in clay diminishes to 18%, Company X has calculated the requisite tonnage of clay through interpolation, as detailed in Table 3. This table illustrates the projected increase in clay consumption, assuming a decline in clay quality to an Al2O3 level of 18%—a rise of 0.3% compared to the current requirement. From these interpolations, which consider the previous Al2O3 levels and the capacity based on past clay requirements, it has been determined that the projected clay requirement for the following year would be approximately 1,257,719 tons. This calculation is pivotal in forecasting and planning for potential changes in raw material quality, and ensuring continuous and efficient production.

The analysis of the current clay requirements forms the basis for the subsequent step: a thorough evaluation of each piece of machinery involved in clay processing at Plant IV. This critical assessment aims to identify which machines are operating at full capacity and may not be able to meet clay requirements for the following year. This evaluation is meticulously conducted by comparing the capacity of each machine, specifically focusing on their clay feeding

Table 2. The Percentage of Al2O Content in Clay

| Year | Al2O3 Content in Clay (%) | Clay Consumption (x 1000 ton) |
|---|---|---|
| 2018 | 27.20 | 832.47 |
| 2019 | 25.14 | 900.41 |
| 2020 | 23.81 | 950.79 |
| 2021 | 23.41 | 967.09 |

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Table 3. The Projected Clay Consumption for The Following Year

| Year | Al2O3 Content in Clay (%) | Clay Consumption (x 1000 ton) |
|---|---|---|
| 2021 | 23.41 | 967.09 |
| The following year | 18 | 1,257.72 |

capacities measured in tons per hour, against the determined clay requirements. Such a comparison is essential to ensure that the machinery can continue to support production needs as clay requirements evolve. Furthermore, the comprehensive evaluation of machines processing clay at Plant IV included calculating the mechanical availability of each machine. This calculation involves a thorough analysis of operating hours, breakdown hours, and standby hours. The result of this calculation is expressed as a percentage, reflecting the machine's operational efficiency by accounting for time lost due to mechanical issues. The evaluation process further extends to an in-depth assessment of each machine's mechanical availability and utility in processing clay. This extensive analysis is systematically presented in Tables 4, 5, and 6. Notably, Table 8 offers a comparison between the maximum capacity of each machine and the projected clay requirements, providing a clear view of the machinery's capability to meet future demands.

The insights gained from observations and direct interviews with the Design and Engineering Department at Company X have been instrumental in establishing retrofitting criteria for machinery. It is understood that a machine is deemed in need of retrofitting, either through replacement or new installation, when its mechanical availability falls below 70%. This benchmark serves as a clear standard for determining the retrofitting needs of each piece of machinery related to clay material processing. By referring to Table 5, which lists the mechanical availability of each machine, it becomes straightforward to identify which machines have dipped below the 70% threshold and thus require retrofitting attention. This methodical approach ensures that machinery maintenance and upgrades are both timely and efficient.

Table 6 provides a detailed comparison of several critical aspects of the machinery at Plant IV: the maximum capacity of each machine, the required clay to be processed, and each machine's mechanical availability and utility relative to its capacity. This comparison is crucial to determine if the maximum capacity of each machine is sufficient to process the required clay quantity. The analysis reveals that 17 machines currently fall short in adjusting to the clay requirement. Among these, machines like the Apron Feeder, which transports clay material from the Crusher, and the belt conveyors that move material from the loading area to storage and from storage to the Raw Mill, along with

Table 4. Analysis of Mechanical Availability of Machinery Involved in Plant IV - Company X in 2021

| No. | Machine | OP (hr./yr.) | B&ST (hr./yr.) | MA (Avg. 2021) | Decision | No. | Machine | OP (hr./yr.) | B&ST (hr./yr.) | MA (Avg. 2021) | Decision |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Hopper | 7191 | 9 | 99.88% | - | 13 | 25121 | 6953 | 247 | 96.57% | - |
| 2 | Apron Feeder | 4577 | 2623 | 63.57% | Retrofit | 14 | 4R1J07 | 7020 | 180 | 97.50% | - |
| 3 | Crusher | 4658 | 2542 | 64.69% | Retrofit | 15 | Feeder Clay 4R1 | - | 7200 | 0.00% | Retrofit |
| 4 | 4C1J02 | 4249 | 2951 | 59.01% | - | 16 | Feeder Clay 4R2 | - | 7200 | 0.00% | Retrofit |
| 5 | 4C1J03 | 4114 | 3086 | 57.14% | - | 17 | 4R1J06 | 4979 | 2221 | 69.15% | Retrofit |
| 6 | 4C1J04 | 4952 | 2248 | 68.78% | Retrofit | 18 | 4R2J06 | 5030 | 2170 | 69.86% | Retrofit |
| 7 | 4C1J05 | 4916 | 2284 | 68.28% | Retrofit | 19 | 4R1J03 | 5135 | 2065 | 71.32% | - |
| 8 | 25118 | 5010 | 2190 | 69.58% | Retrofit | 20 | 4R1J04 | 4977 | 2223 | 69.13% | Retrofit |
| 9 | 25320 | 4974 | 2226 | 69.08% | Retrofit | 21 | 4R1J05 | 5023 | 2177 | 69.76% | Retrofit |
| 10 | 25420 | 4878 | 2322 | 67.75% | Retrofit | 22 | 4R2J03 | 5990 | 1210 | 83.19% | - |
| 11 | 25120 | 4902 | 2298 | 68.08% | Retrofit | 23 | 4R2J04 | 5028 | 2172 | 69.83% | Retrofit |
| 12 | 25220 | 4950 | 2250 | 68.75% | Retrofit | 24 | 4R2J05 | 5000 | 2200 | 69.44% | Retrofit |

Note: OP – Operating Time; B&ST – Breakdown & Standby Time; MA – Mechanical Availability
Production days/year = 360 days; Production hours/day = 24 hours; Maintenance days/year = 60 days.

Table 5. The Utility of Each Machines in Plant IV - Company X

| No. | Machine | Clay Req. (x 1000 ton) | Clay Targeted (x 1000 ton) | | Utility (%) | No. | Machine | Clay Req. (x 1000 ton) | Clay Targeted (x 1000 ton) | | Utility (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Designed | Actual | | | | | Designed | Actual | |
| 1 | Hopper | 1,257.72 | 1,258.43 | 1,258.43 | 100.06 | 13 | 25121 | 1,257.72 | 1,272.39 | 1,272.39 | 101.17 |
| 2 | Apron Feeder | 1,257.72 | 343.28 | 343.26 | 27.29 | 14 | 4R1J07 | 1,257.72 | 1,284.66 | 1,284.66 | 102.14 |
| 3 | Crusher | 1,257.72 | 232.90 | 232.90 | 18.52 | 15 | Feeder Clay 4R1 | - | - | - | - |
| 4 | 4C1J02 | 1,257.72 | 1,372.43 | 1,372.43 | 109.12 | 16 | Feeder Clay 4R2 | - | - | - | - |
| 5 | 4C1J03 | 1,257.72 | 1,583.89 | 1,583.89 | 125.93 | 17 | 4R1J06 | 1,593.11 | 652.22 | 164.31 | 40.94 |
| 6 | 4C1J04 | 1,257.72 | 569.48 | 569.48 | 45.28 | 18 | 4R2J06 | - | | 487.91 | |
| 7 | 4C1J05 | 1,257.72 | 467.02 | 467.02 | 37.13 | 19 | 4R1J03 | 3,306.26 | 3,265.60 | 1,396.72 | 98.77 |
| 8 | 25118 | 1,257.72 | 375.75 | 375.75 | 29.88 | 20 | 4R1J04 | 3,306.26 | 2,129.25 | 746.55 | 64.40 |
| 9 | 25320 | 1,257.72 | 740.70 | 373,05 | 58.89 | 21 | 4R1J05 | 3,306.26 | 2,058.45 | 753.45 | 62.26 |
| 10 | 25420 | 1,257.72 | 737.10 | 365.85 | 58.61 | 22 | 4R2J03 | - | - | 1,868.88 | - |
| 11 | 25120 | - | - | 367.65 | - | 23 | 4R2J04 | - | - | 1,382.70 | - |
| 12 | 25220 | - | - | 371.25 | - | 24 | 4R2J05 | - | - | 1,305.00 | - |
| Clay Consumption/year (x 1000 ton) | | | | | | | 1,257.72 | | | | |
| Iron Sand Consumption/year (x 1000 ton) | | | | | | | 335.39 | | | | |
| Limestone and Silica Stone Consumption/year (x 1000 ton) | | | | | | | 1,713.14 | | | | |

Note: RM Req. – Raw Material Required; RM Targeted – Raw Material Targeted

Table 6. Comparison of Machine Capacity and Availability with Clay Consumption (x 1000 ton)

| No. | Machine | Maximum Capacity | RM Req. | Machine Availability | No. | Machine | Maximum Capacity | RM Req. | Machine Availability |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Hopper | 1,260.00 | 1,257.72 | 1,258.43 | 10 | 25220 & 25420 | 1,080.00 | 1,257.72 | 740.70 |
| 2 | Apron Feeder | 540.00 | 1,257.72 | 343.27 | 11 | 25121 | 1,080.00 | 1,257.72 | 737.10 |
| 3 | Crusher | 360.00 | 1,257.72 | 232.90 | 12 | 4R1J07 | 1,317.60 | 1,257.72 | 1,272.39 |
| 4 | 4C1J02 | 2,325.60 | 1,257.72 | 1,372.43 | 13 | Feeder Clay 4R1 | 1,317.60 | 1,257.72 | 1,284.66 |
| 5 | 4C1J03 | 2,772.00 | 1,257.72 | 1,583.89 | 14 | Feeder Clay 4R2 | - | - | - |
| 6 | 4C1J04 | 828.00 | 1,257.72 | 569.48 | 15 | 4R1J06 & 4R2J06 | - | - | - |
| 7 | 4C1J05 | 684.00 | 1,257.72 | 467.02 | 16 | 4R1J03 & 4R2J03 | 936.00 | 1,515,61 | 652.22 |
| 8 | 25118 | 684.00 | 1,257.72 | 375.75 | 17 | 4R1J04 & 4R2J04 | 4,204.80 | 3,228.75 | 3,265.60 |
| 9 | 25120 & 25320 | 1,080.00 | 1,257.72 | 740.70 | 18 | 4R1J05 & 4R2J05 | 3,297.60 | 3,228.75 | 2,129.25 |

the feeding machines for each Raw Mill, are identified as requiring retrofitting. This determination is based on the inability of these machines to handle the projected clay for 2021, even when operating at optimal conditions, highlighting the need for urgent upgrades or replacements to meet current and future demands.

The evaluation of machines affected by capacity shortage issues at Plant IV has identified 17 machines that are impacted. The urgency of retrofitting these machines is underscored by the potential for a cascading sequence of breakdowns and significant opportunity losses if not addressed promptly. This aspect of opportunity loss will be further quantified in the financial analysis, particularly as it pertains to the planned investment project's implementation.

Specifically, the opportunity loss due to the capacity shortage of machines involved with clay processing at Plant IV is calculated based on the downtime of the Raw Mill. This calculation takes into account the journey of clay to the Raw Mill, where it is combined with other materials to produce the Raw Mix. Neglecting to resolve these capacity issues could lead to frequent breakdowns and consequent opportunity losses. The precise calculation of opportunity

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loss, especially focusing on the downtime of Raw Mills 4R1 and 4R2 due to issues related to clay processing, is comprehensively presented in Tables 7 and 8. These tables detail the extent of impact and underscore the critical need for timely intervention in machine retrofitting to mitigate these losses.

In summary, the technical evaluation conducted at Plant IV highlights a pressing need to retrofit 17 machines to avert a potential sequence of breakdowns. This necessity is not just a matter of operational efficiency but also has significant financial implications. The calculated opportunity loss due to the capacity shortage, particularly in Raw Mill operations, underscores the economic impact of delayed action. This analysis vividly illustrates the importance of timely upgrades and interventions to maintain continuous and efficient production, thereby minimizing financial losses.

Next, we explore the outcomes and deliberations arising from the financial analysis of the investment project focused on retrofitting production machinery at Plant IV. The projected investment, amounting to IDR28,556,784,462.84, is allocated across various domains: mechanical requirements, civil works, electrical and instrumentation, and engineering activities.

The projected savings, totaling IDR13,761,814,739 in the first year as per the financial analysis, demonstrate the economic advantages of rectifying capacity-mismatch issues via the planned investment, as detailed in Appendix A.3. Post-retrofit operational costs encompass maintenance, energy consumption, and depreciation. Specifically, the total costs are estimated at IDR28,556,784,460 as initial investment. The depreciation analysis indicates an annual cost of IDR839,630,112, leading to a residual asset value of IDR20,160,483,340 after the 10-year investment period, as outlined in Appendix A.4. This comprehensive financial breakdown illustrates the cost-effectiveness and long-term financial sustainability of the retrofitting initiative.

Table 7. Factors Causing Opportunity Loss in Raw Mill Production Process of Plant IV - Company X

| **Problems** | **General Reasons** | **Details** |
|---|---|---|
| Overdrawn Clay | Supply Clay is not fluent (transportation) | Block in some transportation machines involved |
| | | Towing by the problematic Bucket Chain Elevator |
| Unplanned breakdown of machines | Repair, replacement and checking of mechanical equipment | Vibration (Need to be Checked) |
| | | Repair of mechanical equipment (belt torn, block overcoming, replacement of parts of machines involved) |
| Laboratory Request | Clay (shortage/supply to mill is not fluent) | Lack of clay feeds |

Table 8. Opportunity Loss of Raw Mill in Plant IV - Company X

| **Raw Mill 4R1** | | | | **Raw Mill 4R2** | | | |
|---|---|---|---|---|---|---|---|
| **Month** | **Breakdown (in hours)** | **Prod. Capacity (ton/hour)** | **Breakdown (in ton)** | **Month** | **Breakdown (in hours)** | **Prod. Capacity (ton/hour)** | **Breakdown (in ton)** |
| Jan | 16.47 | 104 | 1,710.02 | Jan | 17 | 232 | 3,940.93 |
| Feb | 10.67 | 100 | 1,071.84 | Feb | 21.8 | 243 | 5,298.23 |
| Mar | 24.6 | 104 | 2,565.14 | Mar | 20.27 | 241 | 4,887.84 |
| Apr | 10.12 | 101 | 1,020.75 | Apr | 15.67 | 248 | 3,891.73 |
| May | 3.87 | 92 | 355.76 | May | 15.47 | 207 | 3,196.82 |
| Jun | 0 | 93 | - | Jun | 0 | 197 | - |
| Jul | 0 | 123 | - | Jul | 0 | 188 | - |
| Aug | 24.12 | 123 | 2,967.62 | Aug | 15.52 | 223 | 3,465.52 |
| Sept | 28.35 | 124 | 3,517.67 | Sept | 16.58 | 214 | 3,542.66 |
| Oct | 16.95 | 108 | 1,824.53 | Oct | 25.4 | 223 | 5,662.69 |
| Nov | 66.15 | 121 | 8,007.97 | Nov | 2.45 | 220 | 539 |
| Dec | 18.88 | 123 | 2,323.64 | Dec | 8.37 | 223 | 1,868.62 |
| Total Breakdown (in ton) | | | 36,294.04 | Total Breakdown (in Ton) | | | 36,294.04 |

An in-depth profit-loss analysis, detailed in Appendix A.5, forecasts a substantial first-year post-implementation profit of IDR11,674,480,782, highlighting the positive financial impact of the planned investment. The feasibility of the investment project, as documented in Appendix A.6, is assessed using several key financial metrics:

1. Net Present Value (NPV): The NPV is calculated to be IDR252,784,069,179.53. A positive NPV strongly suggests that the project is financially viable and worthwhile.
2. Internal Rate of Return (IRR): The IRR stands at 74.64%, significantly higher than the Minimum Attractive Rate of Return (MARR) of 17.01%. This high IRR indicates that the investment is not only feasible but also potentially very profitable.
3. Payback Period (PP): The investment's payback period is estimated at 2.02 years, which is well within the 10-year horizon, further affirming the project's feasibility and financial soundness.
4. Profitability Index (PI): With a PI of 8.852, which is greater than 1, this metric reinforces the attractiveness and feasibility of the investment, indicating that the returns far outweigh the costs.

The results of this analysis clearly affirm the financial viability of the proposed investment project. The significant savings anticipated from reducing opportunity loss, along with detailed cost calculations and profit forecasts, provide a strong basis for expecting a positive financial outcome. Key feasibility metrics, including Net Present Value (NPV), Internal Rate of Return (IRR), payback period, and profitability index, consistently reinforce the soundness of the decision to retrofit production machinery at Plant IV. This thorough financial analysis lays a solid foundation for informed decision-making, underscoring that the investment is not merely financially prudent but also strategically beneficial for the company.

## CONCLUSION

The study identified a critical need for retrofitting machines due to the degradation of clay quality, impacting the Alumina Modulus (ALM) in cement production. Evaluation of machinery involved in clay processing revealed 17 machines incapable of meeting the future clay capacity requirements. The financial analysis demonstrated the feasibility and profitability of the planned investment project, indicating a positive outlook for stakeholders and investors. The research outcomes underscore the broader significance of strategic investments in machinery and infrastructure for long-term competitiveness and sustainability in industrial operations. The implications of the research findings in the industrial engineering domain are the identified need for retrofitting highlights the intersection of industrial engineering and sustainable manufacturing practices. Retrofitting these machines not only ensures optimal performance but also contributes to the overall efficiency and sustainability of cement production processes. The study underscores the importance of proactive maintenance and technological upgrades in mitigating production disruptions, emphasizing the role of industrial engineering in enhancing operational resilience. While this study provides valuable insights, there are opportunities for future research: Investigating the integration of advanced technologies, such as Industry 4.0 solutions, in retrofitting processes could be explored for enhanced efficiency and adaptability and comparative studies across similar industrial settings could offer valuable benchmarks for evaluating the effectiveness of retrofitting strategies and their broader applicability.

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## CONFLICT OF INTEREST

The authors affirm that there are no conflicts of interest pertaining to this manuscript. This statement includes the absence of any financial, personal, or professional affiliations that could be construed as influencing the research

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process, its findings, or the decision to publish these results.

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## APPENDIX

A.1 Estimated Availability of Clay Reserves (Radius of 20 – 50 km) from Company X in 2021

| No. | Area | High-grade Volume (x 1000 ton) | Low-grade Volume (x 1000 ton) | Description |
|---|---|---|---|---|
| 1 | Gunung Sarik | 2,043.7 | 1,235.4 | $Al_2O_3$ (23-25%) |
| 2 | Bungus | - | 139.5 | $Al_2O_3$ (18-22%) |
| 3 | Tajarang (can be processed) | - | 311.3 | $Al_2O_3$ (16-22%) |
| | Tajarang (under approval) | - | 18,836.2 | $Al_2O_3$ (16-22%) |
| 4 | Padayo (under approval) | 1,297.6 | - | |
| 5 | Lubuk Selasih | - | 2,500.0 | $Al_2O_3$ (22-24%) |
| 6 | Lubuk Alung | - | 2,500.0 | $Al_2O_3$ (22-25%) |

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A.2 Machineries Capacity of Plant IV - Company X

| No. | Machine | BW (mm) | PM (kW) | n2 Gb (rpm) | SB (m/s) | EC (t/h) | No. | Machine | BW (mm) | PM (kW) | n2 Gb (rpm) | SB (m/s) | EC (t/h) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Hopper | - | - | - | - | 175 | 13 | 4R1J07 | 650 | 11 | 49 | 1 | 93 |
| 2 | Apron Feeder | - | - | - | - | 75 | 14 | 25247 | 650 | 5 | 50 | 1 | 95 |
| 3 | Crusher | - | - | - | - | 50 | 15 | Feeder Clay 4R1 | - | - | - | - | - |
| 4 | 4C1J02 | 1000 | 15 | 29.2 | 0.96 | 323 | 16 | Feeder Clay 4R2 | - | - | - | - | - |
| 5 | 4C1J03 | 1200 | 7.5 | 30 | 0.8 | 385 | 17 | 4R1J06 | 650 | 11 | 17.2 | 0.4 | 33 |
| 6 | 4C1J04 | 650 | 15 | 48.14 | 1.3 | 115 | 18 | 4R2J06 | 650 | 11 | 51 | 1.1 | 97 |
| 7 | 4C1J05 | 650 | 7.5 | 50 | 1 | 95 | 19 | 4R1J03 | 800 | 30 | 59.3 | 1.6 | 272 |
| 8 | 25320 | 650 | 5.5 | 50 | 1 | 95 | 20 | 4R1J04 | 800 | 11 | 50 | 1 | 183 |
| 9 | 25420 | 650 | 5.5 | 50 | 1 | 95 | 21 | 4R1J05 | 800 | 5.5 | 50 | 1 | 183 |
| 10 | 25120 | 650 | 5.5 | 50 | 1 | 95 | 22 | 4R2J03 | 800 | 30 | 54 | 1.8 | 312 |
| 11 | 25220 | 650 | 5.5 | 50 | 1 | 95 | 23 | 4R2J04 | 800 | 30 | 60 | 1.6 | 275 |
| 12 | 25121 | 800 | 7.5 | 19.7 | 0.4 | 72 | 24 | 4R2J05 | 800 | | 89 | 1.5 | 261 |

Note: BW – Belt Width; PM – Power Motor; n2 Gb – n2 Gearbox; SB – Speed Belt; EC – Existing Capacity

A.3 Projected Investment Saving

**Increase in cement price = 3%/year**
**Increase in production volume of raw mix = 3%/year**

| Year | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Opportunity Loss of Raw Mix (ton) | 61,658.99 | 63,508.76 | 65,414.02 | 67,376.44 | 69,397.73 |
| CF ton Raw Mix / ton Clinker | 1,642 | 1,642 | 1,642 | 1,642 | 1,642 |
| Opportunity Loss of Clinker (ton) | 37,551.15 | 38,677.68 | 39,838.02 | 41,033.16 | 42,264.15 |
| CF ton Clinker / ton Cement | 0,716 | 0,716 | 0,716 | 0,716 | 0,716 |
| Opportunity Loss of Cement (ton) | 52,445.74 | 54,019.11 | 55,639.69 | 57,308.88 | 59,028.14 |
| Profit of Cement Sold (x IDR1,000) | 262.40 | 341.12 | 443.46 | 576.49 | 749.44 |
| Opportunity Loss of Cement (x IDR1,000) | 13,761,814.74 | 18,427,069.94 | 24,673,846.64 | 33,038,280.66 | 44,238,257.79 |
| **Saving (x IDR1000)** | 13,761,814.74 | 18,427,069.94 | 24,673,846.64 | 33,038,280.66 | 44,238,257.79 |
| **Year** | **6** | **7** | **8** | **9** | **10** |
| **Opportunity Loss of Raw Mix (ton)** | 71,479.67 | 73,624.06 | 75,832.78 | 78,107.76 | 80,450.99 |
| **CF ton Raw Mix / ton Clinker** | 1.642 | 1.642 | 1.642 | 1.642 | 1.642 |
| **Opportunity Loss of Clinker (ton)** | 43,532.07 | 44,838.04 | 46,183.18 | 47,568.67 | 48,995.73 |
| **CF ton Clinker / ton Cement** | 0.716 | 0.716 | 0.716 | 0.716 | 0.716 |
| **Opportunity Loss of Cement (ton)** | 60,798.99 | 62,622.96 | 64,501.65 | 66,436.69 | 68,429.80 |
| **Profit of Cement Sold (x IDR1,000)** | 974.28 | 1,266.56 | 1,646.53 | 2,140.486 | 2,782.63 |
| **Opportunity Loss of Cement (x IDR1,000)** | 59,235,027.19 | 79,315,701.41 | 106,203,724.19 | 142,206,786.69 | 190,414,887.37 |
| **Saving (x IDR1000)** | 59,235,027.19 | 79,315,701.41 | 106,203,724.19 | 142,206,786.69 | 190,414,887.37 |

A.4 Depreciation Cost Calculation

| Investment | Total | Total Investment Cost (x IDR1,000) | Useful Lifetime (Year) | Residual Value (x IDR1,000) |
|---|---|---|---|---|
| Mechanical Scope | 1 lot | 18,837,010.18 | 30 | 627,900.34 |
| Civil Scope | 1 lot | 8,730,801.72 | 30 | 174,616.03 |
| Elinst Scope | 1 lot | 988,972.56 | 15 | 65,931.50 |
| **Total** | | **28,556,784.46** | | **868,447.87** |

A.4 (Cont.)

| Investment | Total | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 |
|---|---|---|---|---|---|---|---|
| Mechanical Scope | 1 lot | 606,970.33 | 606,970.33 | 606,970.33 | 606,970.328 | 606,970.33 | 606,970.33 |
| Civil Scope | 1 lot | 171,123.71 | 171,123.71 | 171,123.71 | 171,123.71 | 171,123.71 | 171,123.71 |
| Elinst Scope | 1 lot | 61,536.07 | 61,536.07 | 61,536.07 | 61,536.07 | 61,536.07 | 61,536.07 |
| **Total** | | **839,630.11** | **839,630.11** | **839,630.11** | **839,630.11** | **839,630.11** | **839,630.11** |

| Investment | Total | Year 7 | Year 8 | Year 9 | Year 10 | End Salvage Value (x IDR1,000) |
|---|---|---|---|---|---|---|
| Mechanical Scope | 1 lot | 606,970.33 | 606,970.33 | 606,970.33 | 606,970.33 | 12,767,306.90 |
| Civil Scope | 1 lot | 171,123.71 | 171,123.71 | 171,123.71 | 171,123.71 | 7,019,564.58 |
| Elinst Scope | 1 lot | 61,536.07 | 61,536.07 | 61,536.07 | 61,536.07 | 373,611.86 |
| **Total** | | **839,630.113** | **839,630.113** | **839,630.11** | **839,630.11** | **20,160,483.34** |

Note: TIC – Total Investment Cost; UL - Useful Lifetime; RV - Residual Value

A.5 Profit-loss Analysis (x IDR1,000)

| No. | Details | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|---|
| 1 | Saving | 13,761,814.74 | 18,427,069.93 | 24,673,846.643 | 33,038,280.656 | 44,238,257.798 |
| 2 | Operational Cost | 2,087,333.96 | 2,101,612.35 | 2,183,240.261 | 2,197,518.654 | 2,283,861.032 |
| **Earn** | | **11,674,480.78** | **16,325,457.57** | **22,490,606.382** | **30,840,762.002** | **41,954,396.765** |

| No. | Details | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|
| 1 | Saving | 59,235,027.191 | 79,315,701.41 | 106,203,724.19 | 142,206,786.69 | 190,414,887.38 |
| 2 | Operational Cost | 2,298,139.424 | 2,389,526.28 | 2,403,804.67 | 2,500,589.13 | 2,514,867.52 |
| **Earn** | | **56,936,887.77** | **76,926,175.13** | **103,799,919.51** | **139,706,197.56** | **187,900,019.86** |

A.6 Feasibility Analysis (x IDR1,000)

| No. | Details | Year 0 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|---|---|
| 1 | Investment | -28,556,784.46 | - | - | - | - | - |
| 2 | Earn | | 11,674,480.78 | 16,325,457.59 | 22,490,606.38 | 30,840,762.00 | 41,954,396.76 |
| | **Total Proceed** | **-28,556,784.46** | **11,674,480.78** | **16,325,457.59** | **22,490,606.38** | **30,840,762.00** | **41,954,396.76** |
| | **Cum. Proceed** | | **-16,882,303.68** | **-556,846.09** | **21,933,760.29** | **52,774,522.29** | **94,728,919.05** |
| | | | -14,940,091.75 | -492,784.15 | 19,410,407.33 | 46,703,117.07 | 83,830,901.82 |
| **No.** | **Details** | | **Year 6** | **Year 7** | **Year 8** | **Year 9** | **Year 10** |
| 1 | Investment | - | - | - | - | - | - |
| 2 | Earn | - | 56,936,887.77 | 76,926,175.13 | 103,799,919.51 | 139,706,197.56 | 187,900,019.86 |
| | **Total Proceed** | **-** | **56,936,887.77** | **76,926,175.13** | **103,799,919.51** | **139,706,197.56** | **187,900,019.86** |
| | **Cum. Proceed** | **-** | **151,665,806.82** | **228,591,981.95** | **332,391,901,46** | **472,098,099,02** | **659,998,118.88** |
| **Feasibility Analysis** | | | | | | | |
| **IRR** | | **74.64%** | | | | | |
| **NPV** | | **252,784,069.18** | | | | | |
| **PBP** | | **2.024** | | | | | |
| **PI** | | **8.852** | | | | | |
| **Interest** | | **13.00%** | | | | | |


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