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# A Comparative Analysis of Non-Cyanide and Cyanide Gold Leaching Technologies: Lessons Learned from the Failed CLINN GEM Facility and Promising Results of the REVIVE SSMB Project in Itogon, Benguet

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Prince Chukunalu Edike[1,4,6], ORCID No. 0000-0002-9351-7158
Melissa May M. Boado[1], Maria Corazon D. Ocampo[3,6], Scarlet Gwen Facsoy[2], Jason Leung[5], Rancel Banta[2]

[1]Department of Chemical Engineering, Saint Louis University, Baguio City, Philippines
[2]Department of Mining Engineering, Saint Louis University, Baguio City, Philippines
[3]Department of Industrial Engineering, Saint Louis University, Baguio City, Philippines
[4]Leverson Brothers Corporation, Pasig City, Philippines
[5]Benguet State University, La Trinidad, Benguet, Philippines
[6]Strategic Integrated Solutions Industrial Design Services, Baguio City, Philippines

Abstract

This paper presents a comparative analysis of a non-cyanide gold leaching technologies implemented in the small-scale mining community of Itogon, Benguet against a potential gold recovery method with Free Cyanide decontamination and Sodium Cyanide recovery system. The study evaluates the failed CLINN GEM facility and the successful REVIVE SSMB project, focusing on technology readiness and acceptance, operational efficiency, and community engagement. The results demonstrate that the failure of the CLINN GEM facility was attributed to its low community acceptance, high operating costs, and complexity, hindering its practicality and scalability. In contrast, the REVIVE SSMB project achieved exceptional results through an alternative gold ore leaching process using Cyanidation CIP method, driven by strong community engagement, cost-effectiveness, sustainable wastewater/tailings discharge management system and simplified operation approach even for the recovery of gold from complex and low-grade Au ore from the locality. For a viability assessment, a stochastic model for the technology feasibility and project optional valuation under diverse uncertainty consideration for community adoption and expansion presentable to potential investors or for the option right to accept and manage the technology as demonstrated. This research simulated the viability of the REVIVE SSMB approach with a high predictability using Monte Carlo Model through Real Option Analysis; and under the worst-case scenario at 50th percentile (median) 74.53% recovery was achieved. Repeatedly with a similar 50th percentile simulation under an optimized condition with pulp density of 44-50% and 3kg per ton of activated carbon loading during flotation yielded a gold recovery of 91%. Hence, it arguably viable, coupling with the 98 to 99% free cyanide decontamination rate and the 55% NaCN recovery successful discharge management system under the REVIVE SSMB 6 months project model.

Keywords: Gold Leaching, Cyanidation, Recovery, CLINN GEM, REVIVE SSMB, Cyanide decontamination, and Itogon, Benguet



Prince Edike is a graduate of Doctor of Philosophy in Environmental Management and Engineering at Central Luzon State University in Nueva Ecija, Philippines and a Master in Environmental Science graduate at Saint Louis University in Baguio City, Philippines. He is the Co-Founder of Strategic Integrated Solutions Industrial Design Services (SISIDS) incubated under the DTI-TBI Program of Saint Louis University. Address correspondence to Prince Chukunalu Edike, Multi-Domain Data-Based Decision-Support Scientist, Research and Development Division, Leverson Brothers Corporation, 245 Dr. Sixto Antonio Avenue, Caniogan Pasig, Manila, 1800 Philippines. Email: britprinx@gmail.com; Edike.prince@clsu2.edu.ph.

## INTRODUCTION

The small-scale mining community in Itogon Benguet has long sought alternatives to cyanide-based gold ore leaching technologies due to environmental concerns. The CLINN GEM facility was designed as a non-cyanide leaching solution; however, its inability to gain community acceptance, high operational costs, and complexity led to its abandonment.

This paper highlights the significance of technology readiness and community acceptance in successful technology adoption, exemplified by the achievements of the REVIVE SSMB project.

Technically, it is relevant that the REVIVE team utilizes a functional model to guide its current efforts to revive failed facility under the original funding agency. Hence, we proposed and utilized both qualitative and quantitative research approaches which involve using the Technology Readiness and Acceptance Model (TRAM) to assess the community's readiness and acceptance level towards the technology of CLINN GEM. We resolved to develop a set of models to facilitate the adoption of the facility based on predictive results obtained from the TRAM survey questionnaire while comparing the results of our leaching method to the old one.

According to the Technology Acceptance Model (TAM), as narrated in Edike et al. (2023), an individual's intention to use technology directly influences their actual usage of the technology. As the intention to use the technology increases, the likelihood of actual usage also increases (Burgess & Worthington, 2022). TAM has been applied by various researchers since its formulation, including Davis (1989) and Davis, Bagozzi, & Warshaw (1989). Perceived usefulness plays a crucial role in the Technology Acceptance Model. It refers to an individual's belief in the potential benefits of using a specific technology. This belief is based on the individual's evaluation of the technology's usefulness and the strength of that belief. Additionally, an individual's perception of the ease of use of the technology can influence their perceived usefulness. Addressing this perception can be achieved through various means, such as removing obstacles or creating opportunities for successful use (O'Keefe, 2016).

The Technology Acceptance Model (TAM) has gained widespread acceptance and serves as a precursor model to TRAM. Many researchers have utilized TAM to explore technology acceptance and adoption across various sectors, including smart city facilities, health management with state-of-the-art devices, and technology adoption for learning and teaching (Buyle et al., 2018; Liu et al., 2022; Ndebele & Mbodila, 2022), respectively. We believe that by using this model, we may be able to fully or partially understand why the CLINN GEM failed in Itogon, and in addition, we have comparatively propose to leach the complex gold ore common in the locality which CLINN GEM was unable to recover appreciable Au from hence, the REVIVE SSMB uses the cyanidation method. Nevertheless, our approach entails treatment of the free cyanide contained in the discharge through decontamination and recovery of free CN and NaCN respectively.

The historical use of cyanide chemistries in mining and industrial processes has been documented (Deal, 2018; Kuyucak & Akcil, 2013); and it has been reported that the most common cyanide species in gold processing facility with expected tailings slurry are free cyanide anions ranging from 100 to 500 mg/L (SGS, 2003). For a long time, there have been search for alternatives to free CN destruction or recovery due to toxicity concerns however, cyanide destruction processes dominates research community owing to its lower cost (Hai et al., 2023; Bae et al., 2019; Young & Jordan, 2018). The destruction approach includes alkaline chlorination, biological treatment, Caro's acid, hydrogen peroxide, and sulfur dioxide and air are still being used but are not so effective.

In this research, we have designed and implemented free cyanide treatment from gold mine tailings discharges from our pilot project in Itogon. Here, we implement and assess the effectiveness of Na2S2O5 and powdered natural zeolite (60 mesh) in treating discharged mine tailings containing free cyanide, under varying Na2S2O5 concentrations (0.5g/L, 1g/L, 1.5 and 2g/L), while maintaining a constant mix of 5g/L powdered natural zeolite. The treatment was performed at pH 10 with a stirring time of 4 hours. Previous treatment using Na2S2O5 with other reagents was implemented by Kim & KIM, 2011; where Na2S2O5 was involved in heavy metals extraction and decontamination from mine tailings, furthermore, a successful treatment by (Hou et al., 2020; Hewitt et al., 2012;

Maimekov et al., 2014; and Aranguri et al., 2018); wherein, an optimal treatment conditions for decomposing cyanide from leach tailings utilized was 0.5 g/L $Na_2S_2O_5$ at pH 10 for 3 hours, followed by the addition of 2 mL/L $H_2O_2$ at pH 9 for 4 hours, resulting in leaching metal concentrations meeting the backfilling requirements (0.05 mg/L). It is documented by many researcher (González-Valoys et al., 2022) that tailings and sediments around gold mines are highly polluted with heavy metals and total cyanide (T-CN) content, posing a significant ecological risk and acting as a persistent source of pollution in the surrounding areas even after more than 20 years even after mining operations cease. Cacciuttolo, et al. (2023) highlights the crucial need for a comprehensive and interdisciplinary definition of mine tailings of which most tailings contain Cyanide particularly the free CN (Anning et al., 2019). Hence, the previous authors emphasize the potential environmental and socio-environmental risks, drawing from case studies of large-scale copper and gold mining projects in Chile and Peru, and advocating for responsible management practices to mitigate adverse impacts, the generation of acid rock drainage and the importance of adopting high management standards, best available technologies, and environmental practices.

Objectives of the Study. The general objective of this research is to assess the feasibility and potential for the sustainable adoption of a non-cyanide gold leaching capability of CLINN GEM as compared to the integrated Cyanide leaching technologies with decontamination and recovery capabilities approach of the REVIVE SSMB Project for the small-scale mining community in Itogon Benguet, Philippines. To accomplish this goal, below are the three objectives to be explored:

1. To evaluate the reasons behind the failure of the CLINN GEM facility, a non-cyanide gold ore leaching technology using technology readiness and acceptance model towards understanding its abandonment.

2. To present comprehensive analysis and recommendations for the government and relevant stakeholders to support the expansion and sustainable adoption of the successful REVIVE SSMB integrated gold leaching and discharge/waste management approach based on scientific evidence and data-driven analysis.

3. To contribute to the body of knowledge on sustainable mining practices and technology adoption, providing valuable insights for future research and development in the field of small-scale gold ore processing.

## METHODOLOGY

Research Design. The research utilized a mixed-method approach, combining data from the CLINN GEM facility's assessment and reports, questionnaire, and the comprehensive data generated from site operation by the REVIVE SSMB project team. A TRAM-based questionnaire was administered to key stakeholder's "Federation" as they are referred to during focus group discussions to assess technology readiness and acceptance for the technologies. Performance data includes gold recovery rates, Real Option Analysis values and Sensitivity Analysis computations using python programming language upon which the Monte Carlo Simulation were modelled and obtained from the REVIVE SSMB project' field reports.

Data Source. The research methodology employed in this study involved the collection and processing of milled ore obtained from the local vicinity. The ore samples were sent to the Mines and Geosciences Bureau (MGB) laboratory in Baguio City for gold assaying to determine the gold content in grams per metric ton (g/mt). The concentrates were obtained from the loaded carbon during discharge, while the tailings were collected from the containment pond.

The values of gold (Au) in g/mt were analyzed using Atomic Absorption Spectroscopy (ASS) in the MGB laboratory. Additionally, tests for free cyanide and heavy metals were conducted at the Central Luzon Regional Laboratory (CRL) in Pampanga. Pulp density analysis was performed at the laboratory facility of Leverson Brother Corporation. Subsequent sample processing involved oven drying the samples in the Department of Chemical Engineering lab, followed by weighing, which was carried out in the Mining Department lab. The final step of decontamination and recovery treatment was conducted in the laboratory at the Department of Environmental Science, Management, and Engineering in Central Luzon State University, Nueva Ecija, with the assistance of on-the-job training students.

Data Analysis. Statistical tools such as linear regression and descriptive statistics were employed to understand the relationships between variables. Moreover, a Monte Carlo simulation model using Python programming was utilized, integrated within the digital environment of Dr. Prince Edike's Google Colab environment. This simulation model was crucial in generating probabilistic outcomes and exploring uncertainties in the research results. Overall, this comprehensive methodology allowed for rigorous data collection, precise analysis, and accurate modeling to obtain valuable insights into the gold processing facility and its potential for decontamination and recovery. The collaboration between various laboratories and institutions facilitated a robust investigation into the technological aspects of the research topic.

LITERATURES

Monte Carlo Simulation and Real Options: A Case Study of Gold Processing Project in Itogon, Philippines. In the ever-evolving mining industry, the extraction of gold faces new challenges such as increasingly low-grade ore, economic uncertainties, and market conditions influenced by technological advancements. To ensure the viability and success of gold leaching facilities, both small and large-scale projects can benefit greatly from the utilization of tools like real option analysis (ROA). By incorporating flexibility and uncertainties into decision-making processes, real option analysis enables project planners to make informed choices and adapt to changing market dynamics. This article explores the relevance and significance of employing real option analysis for gold leaching facilities, particularly in the context of local communities.

The Changing Mining Landscape. The mining industry is witnessing a shift towards processing lower-grade ore deposits due to the depletion of high-grade reserves. This transition introduces economic challenges, as extracting gold from lower-grade ore requires advanced processing techniques and entails higher costs. Additionally, market conditions driven by technological advancements, such as more efficient production technologies, can significantly impact the profitability of gold leaching facilities. In such a dynamic environment, traditional financial analysis alone may not be sufficient to evaluate the long-term feasibility of projects.

Understanding Real Option Analysis. Real option analysis is a powerful decision-making tool that recognizes the inherent flexibility and uncertainties present in investment opportunities. Unlike traditional capital budgeting techniques, real option analysis considers the value of managerial flexibility, allowing project planners to respond to changing circumstances and capitalize on potential opportunities. By evaluating embedded options within a project, such as the option to expand production capacity, enter new markets, or adapt processing techniques, real option analysis provides a more comprehensive assessment of the project's value. ROA was utilized by Slade, (2001); to provide the valuation of mining investment while address the inherent uncertainty over time, while Moel et al., (2002); detailed the relevance of ROA in decision support for opening closing mines based on obtained datasets. Krychowski & Quélin, (2010); explored the need and importance of ROA in telecommunication projects with uncertain investment ecosystem towards a more holistic strategic risk management. In a more comprehensive review, (Csapi, 2019; and Gorupec et al., 2022); argues that the company’s capital allocation to generate more profit amid uncertainty can be achieved through ROA as it allows risk reduction to be made using the variables most likely to be affected by risk and they documented many works done using ROA. Interestingly, Bogdan et al. (2017) utilize ROA through Monte Carlo Simulation to investigate the risk and uncertainty in steel industry and they argued that such is needed in assets valuation subjected to many investments risk.

Importance for Local Communities. The application of real option analysis holds particular relevance for gold leaching facilities in local communities. These projects not only have economic implications but also impact the social and environmental fabric of the community. By considering uncertainties and potential changes in market conditions, real option analysis assists in identifying the optimal investment strategy for the facility. It helps project planners assess the viability of small and large-scale projects, anticipate potential challenges, and identify alternative courses of action that align with the community's goals and aspirations.

Benefits and Outcomes. Real option analysis offers several key benefits for gold leaching facilities. Firstly, it enables a more accurate assessment of the project's value by incorporating managerial flexibility and responding to uncertainties. Secondly, it helps identify potential risks and opportunities, allowing project planners to make informed decisions regarding investment strategies, production techniques, and market entry points. Thirdly, by considering the social and environmental implications of the project, real option analysis contributes to sustainable development and enhances community engagement.

Formulas and Equations for Real Option Analysis:

1. Annual Cash Flow (ACF):
   - ACF = Projected Annual Net Profit * (1 - Tax Rate)
2. Real Option Value (ROV):
   - ROV = Sum of (ACF t/(1 + r)^t) for t = 1 to T

   Variables:
   - ACF: Annual Cash Flow
   - Projected Annual Net Profit: P664,576
   - Tax Rate: 12%
   - T: Time horizon in years
   - r: Discount rate (e.g., 0.10 for 10%)

The values in the variables above were then fed to a Monte Carlo Simulation Model using python programming language to compute and plot the distribution over the different percentile values, hence, Percentile Values = Percentile (real_option_values, [5, 25, 50, 75, 95]).
RESULTS

CLINN GEM Facility. The CLINN GEM facility experienced significant challenges in community acceptance, with a median Overall TRAM Score of 1.12 as seen the plots of Figure 2 and Figure 3. Community members found the technology complex and difficult to operate, leading to a lack of trust and reluctance to adopt the technology. The high operating costs of the facility further deterred its practicality and scalability, contributing to its ultimate failure.

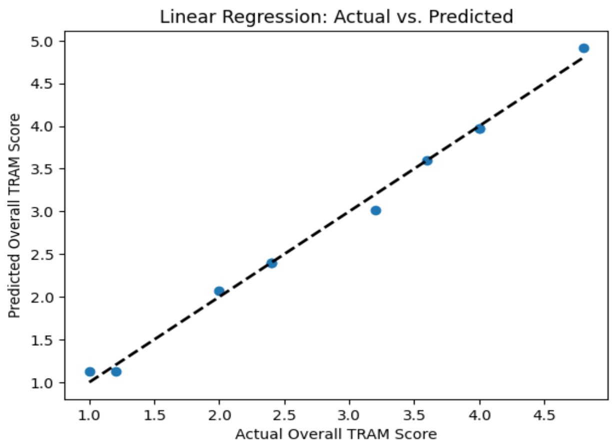


Figure 1

*The linear model of the Overall TRAM Score = 0.18 + 0.18 * Perceived Ease of Use + 0.25 * Perceived Usefulness + 0.07 * Operational Cost + 0.18 * Technical Support and Training + 0.25 * Social Cultural Factors.*

**Legend: Perceived Ease of Use: Very Difficult: 1, Difficult: 2, Neutral: 3, Easy: 4, Very Easy: 5*

***Legend: Perceived Usefulness, *Operational Cost, *Availability of Technical Support and Training, and *Social Cultural Factors: Strongly Disagree: 1, Disagree: 2, Neutral: 3, Agree: 4, Strongly Agree: 5*

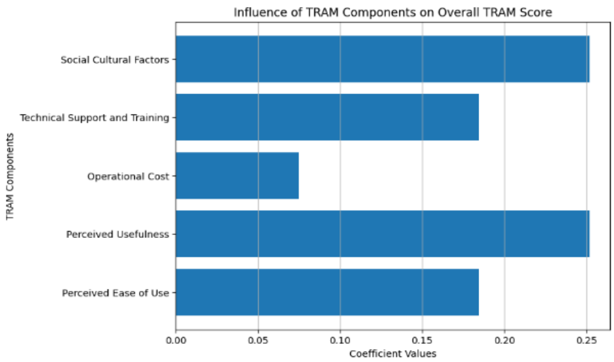


Figure 2

*The TRAM Output Summary bar plot*

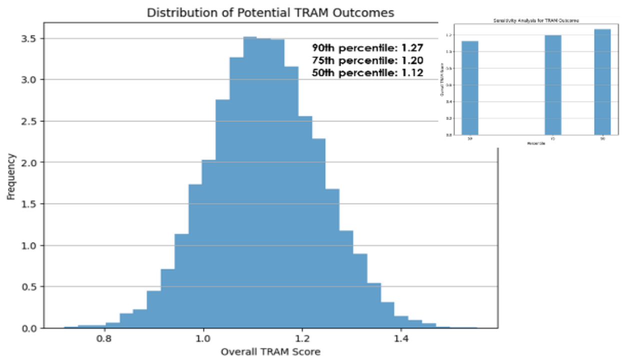


Figure 3

*The Monte Carlo Simulation Distribution of the TRAM Output using 10, 000 iterations.*

REVIVE SSMB Project. The REVIVE SSMB project, on the other hand, achieved remarkable success with the Cyanidation CIP method as seen in Table 1 and Table 2; with their plots in figure 4 and 5. The technology demonstrated exceptional gold recovery rates, averaging 91% from even the lowest grade of gold ore (3 grams per metric ton). The narrow spread between the 25th and 75th percentiles indicated the method's consistency and predictability, reducing the risk associated with gold recovery rates. The high predictability, as evidenced by the 95th percentile reaching close to 100% recovery, instills confidence in investors and stakeholders as seen from the Monte Carlo Simulation plots in figure 6, 7, 8 and 9. An important attention has to be paid to the ore procurement as this variable seem highly sensitive based on the Sensitivity Analysis conducted through the MCS implementation as seen in Figure 10.

Table 1

*The REVIVE SSMB Au Recovery in general*

| ORE | FEED (gram/MT) | CONCENTRATE (Grams/MT) | TAILINGS (Grams/MT) | Gold Recovery (%) | LIXIVIANT USED (2KG/MT) |
|---|---|---|---|---|---|
| L | 2.5 | 460 | 0 | 99 | NaCN |
| L2 | 1.5 | 220 | 0 | 99 | NaCN + CNLite |
| FEED UCAB | 4 | 960 | 1 | 74.99 | NaCN |
| FEED UCAB 2 | 4 | 506 | 1.5 | 25.13 | CNLite |
| J FEED | IN PROGRESS | IN PROGRESS | IN PROGRESS | IN PROGRESS | NaS2S203 |
| | | | | | |
| AGERAGE | 3 | 536.5 | 0.625 | 74.53 | |
| STANDARD DEV | 1.060660172 | 267.538315 | 0.649519053 | 30.15847062 | |

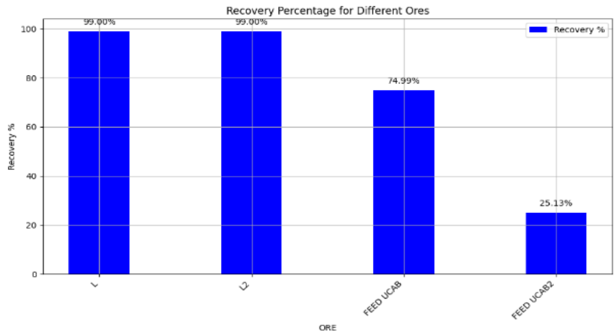


Figure 4

*The Bar Plot of the REVIVE SSMB Au Recovery in general*

Table 2

*The REVIVE SSMB Au Recovery under Optimized Conditions for pulp density and activated carbon content.*

| Without the UBAB2 | | | | | |
|---|---|---|---|---|---|
| ORE | FEED (gram/MT) | CONCENTRATE (Grams/MT) | TAILINGS (Grams/MT) | Gold Recovery (%) | LIXIVIANT USED (2KG/MT) |
| L | 2.5 | 460 | 0 | 99 | NaCN |
| L2 | 1.5 | 220 | 0 | 99 | NaCN + CNLite |
| FEED UCAB | 4 | 960 | 1 | 74.99 | NaCN |
| | | | | | |
| AGERAGE | 2.666666667 | 546.6666667 | 0.333333333 | 90.99666667 | |
| STANDARD DEV | 1.027402334 | 308.2567472 | 0.471404521 | 11.31842254 | |

Table 3

*The Pulp Density values from the different discharges considered.*

| MINE DISCHARGE | TOTAL SLURRY WEIGHT | DRY TAILING WEIGHT | PULP DENSITY |
|---|---|---|---|
| Mother Discharge | 4.75kg | 1.7kg | 35.79% |
| L1 and L2 | 5.5kg | 2.45kg | 44.54% |
| UCAB2 Discharge | 5.3kg | 2.65kg | 50% |
| Cromwell Discharge | 4.0kg | 1.35kg | 33.75% |

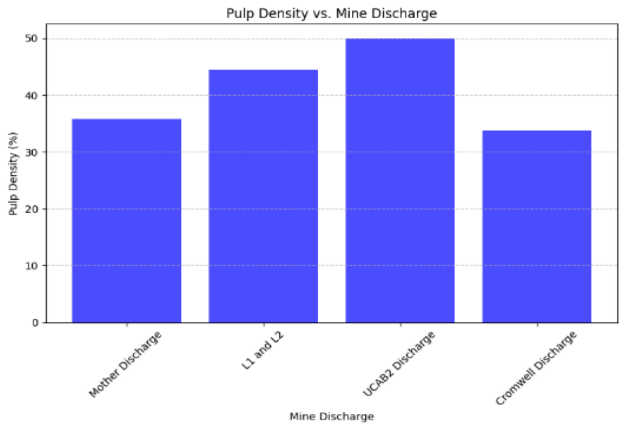


Figure 5

*The bar plot of the pulp densities*

The Discharged Free CN concentration value from the flotation tank is 1.33 or 0.013%. This is considered the control sample CN concentration value. It was obtained using Silver Nitrate titration against the discharged sample (with three drops of Potassium Iodide as indicator) with labels S1 to S4 through three replicates over the varying amount of Activated Carbon content from 15g to 30g per liter seen in Table 4 using distilled water at room temperature.

*Table 4*

*The Reduction and Recovery Results from the REVIVE SSMB Treatment Process for Free Cyanide from thee Discharge tailings*

| Sample # | Free CN Reduction (%) |
|---|---|
| S1 (15g AC) | 27.53 |
| S2 (20g AC) | 40 |
| S3 (25g AC) | 45 |
| S4 (30g AC) | 45 |

**Note: Percentage Reduction/%Decrease = Conc. Value of Discharged (1.33) - New Conc. / Conc. Value of Discharged (1.33) * 100. This makes the percent reduction formula. Thereafter, 25g of AC is considered optimum for a 45% Free CN reduction from our discharge after gold leaching.*

**A molar ratio of 2:1 of NaOH to CN measured at the pH of 7 was used to recover the entire NaCN in the activated carbon loaded solution after 24 hours soaking with the reaction equation as follow; NaOH + CN → NaCN + H2O. This process is called desorption.*

## DISCUSSION

The failure of the CLINN GEM facility underscores the importance of community engagement and acceptance in technology adoption. A lack of trust and unfamiliarity with the technology hindered its successful implementation. Moreover, the high operating costs and complexity further undermined its viability for widespread adoption in the locality. In contrast, the REVIVE SSMB project's success can be attributed to its simplified operation, cost-effectiveness, and strong community engagement. By utilizing the Cyanidation CIP method, the project achieved high gold recovery rates as seen in the Table 1 and 2, making it an attractive and practical alternative to cyanide-based leaching. The involvement of the community in the design and decision-making process fostered a sense of ownership and trust, leading to increased technology acceptance.

From the Monte Carlo simulation distribution in Figure 6, for gold recovery, we observe that the gold recovery percentage follows a normal distribution. The histogram shows that the majority of the simulated gold recovery values are clustered around the mean recovery of approximately 74.53%. This indicates that the recovery process is relatively stable, and the method employed seems to be effective in extracting gold from the ore.

Furthermore, the spread of the distribution, as represented by the standard deviation of approximately 30.16%, indicates the variability in gold recovery. The wider the spread, the greater the uncertainty in achieving consistent recovery rates. However, with a well-defined normal distribution, we can estimate the likelihood of achieving specific gold recovery targets. The 50th percentile (median) is around 74.53%, which suggests that there is a 50% chance of achieving this recovery rate. Investors can be confident in this method's ability to consistently recover gold at or around the median value.

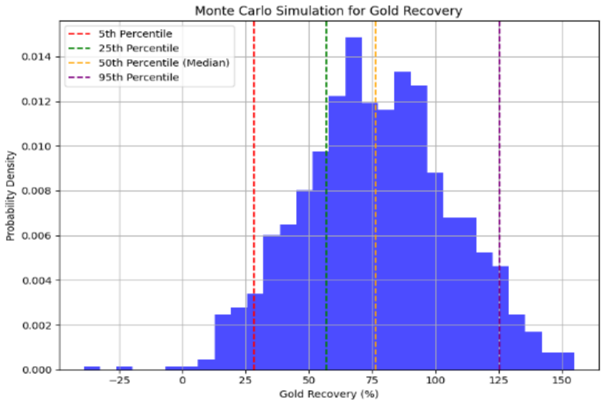


Figure 6

*Au Recovery under Worse Case Scenario Using Monte Carlo Simulation*

Additionally, the results provide insight into the potential risks and opportunities associated with gold recovery. The 5th percentile at approximately 24.2% represents a conservative estimate, indicating that gold recovery is unlikely to fall below this value. Conversely, the 95th percentile at around 124.4% suggests the potential for higher than the expected recovery rates. These extremes indicate the range of possible outcomes, and investors may need to consider risk management strategies to address the variability and capitalize on potential upside.

Overall, the Monte Carlo simulation demonstrates that the gold recovery method shows promise and stability with a mean recovery rate of 74.53%. The distribution provides valuable information to investors, offering a clear understanding of the expected outcomes and associated risks. With this level of insight, investors can make informed decisions and tailor their strategies to maximize returns while accounting for potential variations in gold recovery.

More so, the Monte Carlo simulation (MCS) Model in Figure 7 above demonstrates that the recovery method is highly reliable and efficient, with the 50th percentile (median) gold recovery hovering around an impressive 91%. This indicates that, on average, the recovery process yields exceptional results, offering a high chance of obtaining a significant amount of gold from the ore.

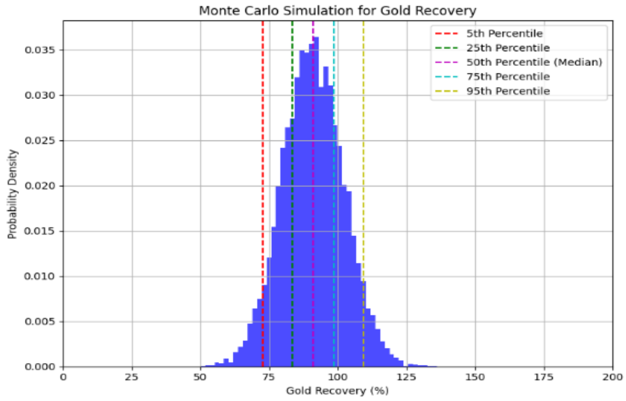


Figure 7

*Au Recovery under Optimized AC and Pulp Density Scenario Using Monte Carlo Simulation*

Moreover, the narrow spread between the 25th and 75th percentiles further highlight the consistency and predictability of the recovery method, reducing the risk associated with volatile gold recovery rates. The fact that the 95th percentile of the distribution reaches close to 100% recovery under the optimized condition of maximizing the activated carbon to 3kg per metric ton of feed in the flotation tank and pulp density of 44-50% as seen in table 3 showcases the potential for exceptional outcomes, providing reassurance to investors that the recovery process is capable of achieving near-perfect results under favorable conditions.

Investors can be assured that the recovery method not only meets but exceeds industry standards, as evidenced by the consistently high gold recovery rates observed in the simulation. The provided average and standard deviation align with the recovery method's stable and robust performance, ensuring that the process is capable of delivering gold recovery within a tight range, mitigating potential financial risks associated with extreme variations. The Monte Carlo simulation's visual representation and clear depiction of the 5th, 25th, 50th, 75th, and 95th percentiles present a comprehensive picture of the potential outcomes, making it easier for investors to weigh the benefits and risks accurately. Overall, the simulation's results underscore the effectiveness, reliability, and profitability of the gold recovery method, making it a compelling and promising investment opportunity for those seeking to capitalize on gold ore processing.

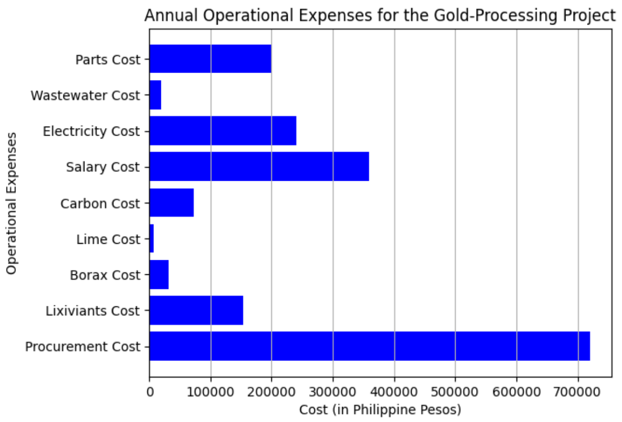


Figure 8

*The bar plot of the annual operations expenses utilized in the MCS Model.*

**Based on the Annual cost at rate of 100 sacks per week (5MT), 15k/ 100 sacks ore procurement min feed grade 3g/ MT, Labor cost – 10k monthly per person (3 men), Wastewater discharge treatment (reagents: sodium metabisulfide + zeolite)*

**Annual Au sale 2.5M, Opex = 1.7M, Profit is around 755k at 1g/ 5MT recovery per week at Php3,500/ g Au as of August average Au price from LME; after tax (12%) = 664k.*

** K means thousand Philippines pesos.*

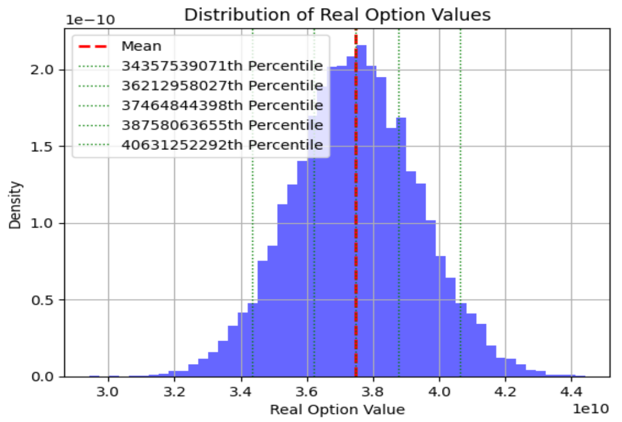


Figure 9

*The distribution Plot of the Real Option Value; as computed through the Monte Carlo Simulation.*

The Real Option Value, as computed through the Monte Carlo simulation seen in figure 9, indicates the potential additional value that can be gained from the flexibility and managerial options associated with the gold-processing pilot project in Itogon, Benguet of the Philippines. The mean Real Option Value of approximately 37,474,851,479.99 pesos suggests that, on average, the project's adaptability and potential future decisions have a significant positive impact on its overall profitability. This means that the option to adjust production capacity, enter new markets, or respond to changing market conditions can lead to substantial value creation over time.

Examining the percentiles further provides valuable insights for prospective investors. The 5th percentile, which stands at approximately 34,357,539,071.87 pesos, indicates the lowest value of the Real Option Value distribution. This value represents the worst-case scenario, suggesting that there is a 5% chance of the project's value falling below this level. Despite the possibility of encountering challenges or adverse market conditions, the 25th percentile at 36,212,958,027.72 pesos demonstrates that there is a higher probability of the project maintaining a favorable value above this threshold. The 50th percentile (37,464,844,398.05 pesos) represents the median Real Option Value, illustrating the most likely outcome based on the simulation. Moreover, the 75th percentile (38,758,063,655.50 pesos) indicates a strong probability of achieving even greater value, suggesting potential profitability and success. Finally, the 95th percentile (40,631,252,292.35 pesos) portrays an optimistic scenario, demonstrating a 5% chance of the project exceeding this upper bound.

In conclusion, the Real Option Analysis reveals that the gold-processing pilot project in Itogon, Benguet, presents promising prospects for prospective investors. The mean Real Option Value of over 37 billion pesos indicates that the flexibility and adaptability of the project have a substantial positive impact on its profitability. Although there is some uncertainty, as indicated by the range of percentiles, the higher percentiles (75th and 95th) show a higher probability of achieving even greater returns, demonstrating the potential for substantial upside. Prospective investors can use this information to assess the risk and reward trade-offs associated with the project and make informed decisions about its viability and potential for long-term success.

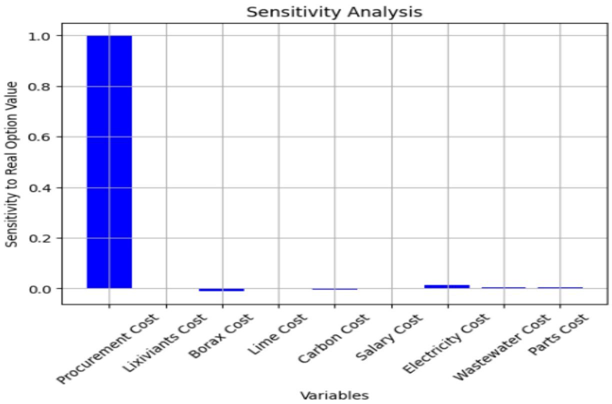


Figure 10

*The Sensitivity Analysis from the Partial Derivative of the Real Option Value with Respect to Each Variable showing the ore procurement as the most sensitive variable.*

Decontamination of Free Cyanide. The REVIVE SSMB team conducted experiments using an optimized mixture of Na2S2O5 and powdered natural zeolite to decontaminate free cyanide from the discharged mine waste water. The experiments involved 4 hours of agitation at room temperature and a pH of 10. The results showed an impressive 99% decontamination of free cyanide from the solution. This decontamination process is highly effective in reducing the concentration of free cyanide in the discharged waste water, contributing to environmental safety and sustainability in the mining area.

Recovery of NaCN from Activated Carbon. In another set of experiments, the REVIVE SSMB team aimed to recover NaCN from the activated carbon used to adsorb cyanide from the solution. The team used NaOH at a molar ratio of 2:1 with cyanide in the discharged mine waste water. See table 4 and a photo of the recovered samples are in Figure 12. The results demonstrated a remarkable 55% recovery of NaCN after 24 hours from the activated carbon.

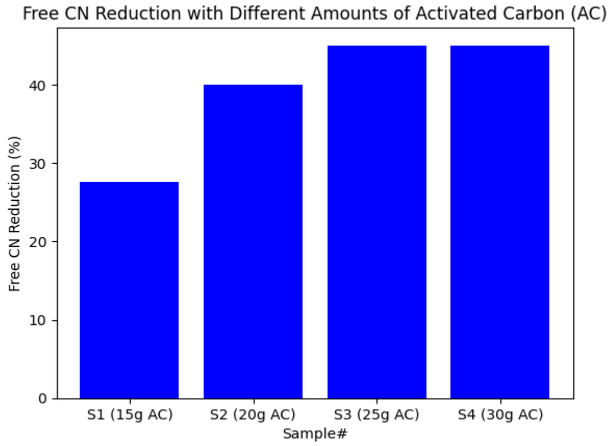


Figure 11

*The bar plot of free CN reduction rate after 24 hours treatment towards recovery approach using activated carbon.*

The results demonstrate that an AC weight of 25g/L is optimal for achieving maximum free cyanide reduction. By adopting the 2:1 molar ratio of NaOH for disorption, the team achieved a significant cyanide recovery rate, making the process both environmentally sustainable and economically viable. This recovery process is significant as it allows for the reuse of the adsorbent material and contributes to reducing the overall consumption of NaCN, thereby promoting sustainable mining practices.

Figure 12

*The photo taken from the representative replica of the 15, 20, 25 and 30g/L of AC over the Free Cyanide contaminated solution towards NaCN recovery in the Department of Mining Laboratory, Saint Louis University, Baguio City, Philippines.*

Conclusion

The comparative analysis of the CLINN GEM facility and the REVIVE SSMB project highlights the critical role of technology readiness, community acceptance, and operational efficiency in successful technology adoption. The positive results from the REVIVE SSMB project indicate its potential for sustainable technology scalability and expansion in the locality. Based on the research findings, we recommend focusing on community engagement, continuous improvement, and capacity building to ensure the successful adoption of the REVIVE SSMB project's gold ore leaching technology. The successful decontamination of free cyanide and the efficient recovery of NaCN by the REVIVE SSMB team highlight the effectiveness of the optimized mixture and recovery process. These results have important implications for the environmental management of discharged mine waste water and the overall efficiency of gold ore leaching operations. The use of Na2S2O5 and powdered natural zeolite as an adsorbent material and the selective recovery of NaCN offer a promising approach to reducing the environmental impact of gold ore processing while enhancing the efficiency of gold recovery methods. These findings are significant steps towards sustainable mining and processing practices and can be valuable in supporting future research and technology adoption in the mining industry.

The data-driven approach presented in this research paper provides valuable insights to support the effort of the REVIVE SSMB project team in their endeavor to promote responsible and sustainable mining practices in Itogon Benguet.

Declaration of Non-Conflict of Interest. The authors declare that there is no conflict of interest regarding the research presented in this article. The study was conducted without any other financial or personal relationships that could potentially bias the findings or influence the interpretation of the results outside the research financial/funding from the Department of Science and Technology - Cordillera Administrative Region (DOST CAR). The research was undertaken solely for academic and scientific purposes, with the aim of contributing to knowledge and advancing the field of technology readiness and acceptance.

Transparency and impartiality have been maintained throughout the research process, and the results have been presented objectively. The authors are committed to upholding the highest standards of ethical conduct and ensuring the accuracy and reliability of the research findings.

This non-conflict of interest statement is provided to assure readers, reviewers, and the scientific community that the research has been conducted with integrity and without any bias, ensuring the validity and credibility of the study's outcomes.

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