Financial Evaluation of Implementing In-Pit Crushing and Conveying Systems for Waste on Open Pit Mines

Research Report by

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STUDENT DECLARATION

I, Ikaneng Serepa, student number 0512571Y, declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering Management in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Signature of Candidate

30th Day of March 2024

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ABSTRACT

The South African mining industry has faced mounting challenges, especially rising expenses that threaten profitability. These escalating costs, driven by various factors including operational expenses such as mining costs, are critical. The distribution of mining costs across activities within the production cycle is crucial, with hauling operations in open pit mines representing a significant portion, as noted by Paricheh et al (2017) at 49%. Due to the substantial economic impact of hauling expenses on mining expenditures, there's a strong incentive to streamline these operations to lower overall costs effectively.

Current research highlights a noticeable transition in the mining sector towards embracing in-pit crushing and conveying (IPCC) systems in open pit mines, acclaimed as a cost-effective substitute for conventional truck and shovel (CTS) systems (Awuah-Offei et al, 2009). This research assessed both the integration and financial viability of implementing a waste IPCC system in the loading and hauling operations of an open pit mine. A mixed-methods approach, combining quantitative data from production records and costs with qualitative insights from expert interviews was used.

The findings of this research indicate that while the IPCC system can be integrated, there remains a degree of reliance on the CTS system for material transportation from the pit to the IPCC system. For the CTS system, 55 rigid dump trucks (RDTs) are required, constituting 57% of the initial capital expenditure of R1.27 billion. Conversely, the IPCC system requires only 31 RDTs, accounting for 29% of the initial capital costs of R1.37 billion. However, despite the substantial reduction in RDTs, the IPCC system requires significant investment in a crusher and conveyor belt system for waste management, which constitutes 32% of its capital costs. Examination of the operating costs over the life of the mine indicates that there are no cost advantages associated with operating an IPCC system compared to the CTS system. Operating expenses for the IPCC system exceed those of the CTS system by 58%, predominantly driven by the operational costs of the crusher and belt system, contributing to 67% of the IPCC system's costs.

The financial assessment results show a positive and acceptable net present value (NPV), internal rate of return (IRR), and payback period for both systems. Nevertheless, the CTS system exhibits superior financial performance, with a NPV of R7.45 billion, an IRR of 83.1%, and a shorter payback period of 1.2 years, and is recommended as a viable option for the mine.

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ABBREVIATIONS AND TERMINOLOGY

ADT: Articulated Dump Truck

ARR: Accounting Rate of Return

Bench: A ledge which forms a single level of operation where ore and/or waste are excavated (Dubey, ND).

CB: Capital Budgeting

CTS: Conventional Truck and Shovel

DCF: Discounted Cashflow

FIPCC: Fixed In-pit Crushing and Conveying

FMPCC: Fully Mobile In-pit Crushing and Conveying

IPCC: In-pit Crushing and Conveying

IRR: Internal Rate of Return

NPV: Net Present Value

OEM: Original Equipment Manufacturer

PBP: Payback

RDT: Rigid Dump Truck

ROM: Run-of-Mine

SIB: Stay-in-Business

SMIPCC: Semi-Mobile In-pit Crushing and Conveying

1 INTRODUCTION

1.1 Background

The South African mining industry has faced significant challenges in recent years, with escalating mining costs posing a substantial threat to the profitability of mining companies. This trend is evident in Figure 1, as highlighted by Price Waterhouse Coopers in 2018. The escalating costs are attributed to various factors, with operating costs, specifically mining costs, playing a pivotal role. In the context of open pit mines, the distribution of mining costs across activities within the production cycle, including drilling, blasting, loading, and hauling, is crucial. Research by Paricheh et al (2017) underscores the significance of hauling, which accounts for a substantial 49% of mining costs. Given this, there is a pressing motivation within the industry to explore avenues for optimizing hauling operations, thereby mitigating the adverse impact on overall mining costs.

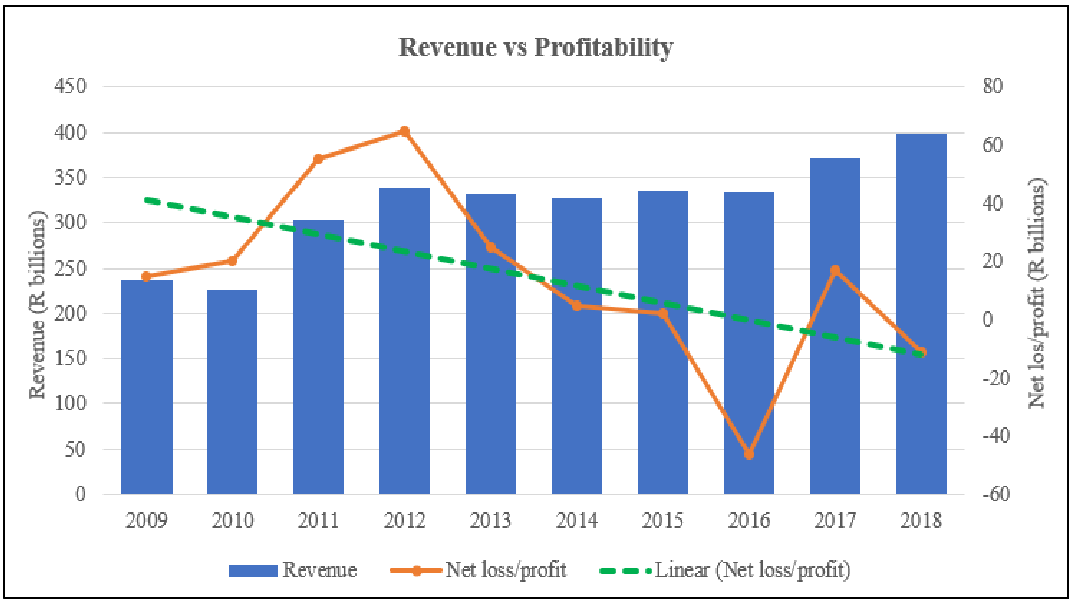

Figure 1: Comparison between Revenue and Profitability in the South African Mining Industry between 2009 and 2018 (Price Waterhouse Coopers, 2018)

In response to the challenging economic landscape, South African mining companies are actively seeking strategies to enhance productivity and reduce operating costs. According to Cassim et al (2019), the adoption of modern technology emerges as a promising avenue for achieving these objectives.

By incorporating advanced technologies into mining operations, there is a potential for substantial cost savings, with estimates suggesting that South African mining companies could achieve a remarkable 20% reduction in operating costs (Cassim et al, 2019). This underscores the urgency and potential benefits associated with embracing innovative solutions and leveraging technological advancements to streamline hauling operations and enhance overall efficiency within the mining sector.

1.2 Problem Statement

An open pit mine operates by extracting both valuable ore and waste materials from mining areas, and the subsequent transportation of these materials is a critical aspect of the mining process. As highlighted by Kennedy (1990), hauling operations play a pivotal role in moving extracted materials from mining sites to designated tipping areas within the mine premises. Significantly, these hauling operations constitute a substantial portion of the total mining costs, accounting for 49% according to the findings of Paricheh et al (2017). Considering the substantial economic influence of hauling expenses on total mining outlays, there is a strong incentive to investigate avenues for enhancing these operations to efficiently lower mining costs.

1.3 Research Question

The question that the research aims to address is as follows:

- What is a practical and financially viable waste material handling system for an open pit mine?

1.4 Research Objectives

The objectives of the research are as follows:

- To assess the integration of a waste in-pit crushing and conveying (IPCC) system into the loading and hauling operations of an open pit mine.
- To evaluate the financial viability of implementing a waste IPCC system on an open pit mine; and
- To provide recommendations based on the findings.

1.5 Research Motivation

Recent literature reveals a notable trend in the mining industry towards the adoption of IPCC systems in open pit mines. According to Awuah-Offei et al (2009), IPCC systems represent a cost-effective alternative to conventional truck and shovel (CTS) systems. Intriguingly, while IPCC systems are commonly employed for handling run-of-mine (ROM) ore (Hashemi et al, 2011), they are not conventionally utilized for managing waste materials. Typically, waste materials are handled using traditional truck and shovel systems. This underscores a potential gap in operational efficiency, prompting the need for research to assess the financial viability of implementing a waste IPCC system in open pit mines and exploring its integration into the loading and hauling operations.

This research aims to fill this knowledge gap by evaluating both the financial feasibility of implementing a waste IPCC system in open pit mines and the integration of such a system into the loading and hauling operations. The research will contribute significantly to the understanding of the financial implications of adopting IPCC for waste material handling and how such a system can be seamlessly integrated into the broader mining operations. Ultimately, the results of this research will furnish decision-makers in the mining industry with valuable insights, enabling them to make informed and strategic decisions regarding the implementation of waste IPCC systems in their open pit mining operations. This research has the potential to drive innovation in mining practices, enhance operational efficiency, and contribute to the sustainable development of the mining industry.

1.6 Delimitations

While this research strives to offer a thorough evaluation of the financial feasibility of implementing the IPCC method, certain limitations must be acknowledged. Firstly, the findings of the research are contingent on the accuracy and availability of financial data, including equipment costs, maintenance expenses, and production forecasts. The reliability of projections is influenced by market volatility and unforeseen economic fluctuations. Furthermore, the research focuses primarily on financial aspects and does not delve extensively into broader environmental or social considerations associated with mining methods. The study is also limited to the specific context of open-pit mining operations, and the findings may not be directly applicable to other mining environments.

Despite these delimitations, the research aims to provide valuable insights into the financial implications of implementing IPCC systems, assisting stakeholders in making informed decisions about optimizing mining practices.

1.7 Assumptions of the Research

The research is based on the assumptions below:

- The haul roads of the investigated open pit mine cannot accommodate RDTs larger than those with a payload of 100 tonnes.
- The crusher and conveyor belt system of the IPCC system has a lengthy economic lifespan, eliminating the need for replacement throughout the mine's operational period.

2 MINE OVERVIEW

2.1 Current Operations

2.1.1 Production and Material Flow

The mine's primary focus is on ore extraction, with a significant output of 2 million tonnes annually. This ore is systematically transported to the processing plant for refinement, contributing to the mine's economic viability. Simultaneously, the mine generates a substantial volume of waste amounting to 18 million tonnes per annum. CTS systems are currently employed to handle this extensive material flow, reflecting industry-standard practices for open-pit mining operations.

2.1.2 Waste Management Strategies

Waste generated during the mining process is meticulously managed to mitigate environmental impact and optimize operational efficiency. 60% of the waste is directed to a surface dump, strategically located approximately 2 km away from the pit. The remaining 40% of waste is backfilled into previously mined-out areas within the pit. Adhering to geotechnical recommendations, the backfill is positioned at a safe distance of 50 meters from active mining faces. This practice aims to maintain stability while concurrently addressing the space constraints posed by the ongoing extraction operations. Geotechnical recommendations guide this waste placement, emphasizing a delicate balance between safety and operational efficiency.

2.2 Future Expansion Plans

2.2.1 Pit Expansion and Increased Material Movement

The mine has ambitious plans for future expansion, with projections indicating a shift towards handling 25 million tonnes of waste annually at steady-state production (see Figure 2). This expansion necessitates the extension of the pit and, consequently, the re-evaluation of waste management strategies. The anticipated increase in material movement poses both opportunities and challenges, requiring a strategic approach to ensure sustainable operations. It is worth noting that Figure 2 was produced by the author using data provided by the mine under study.

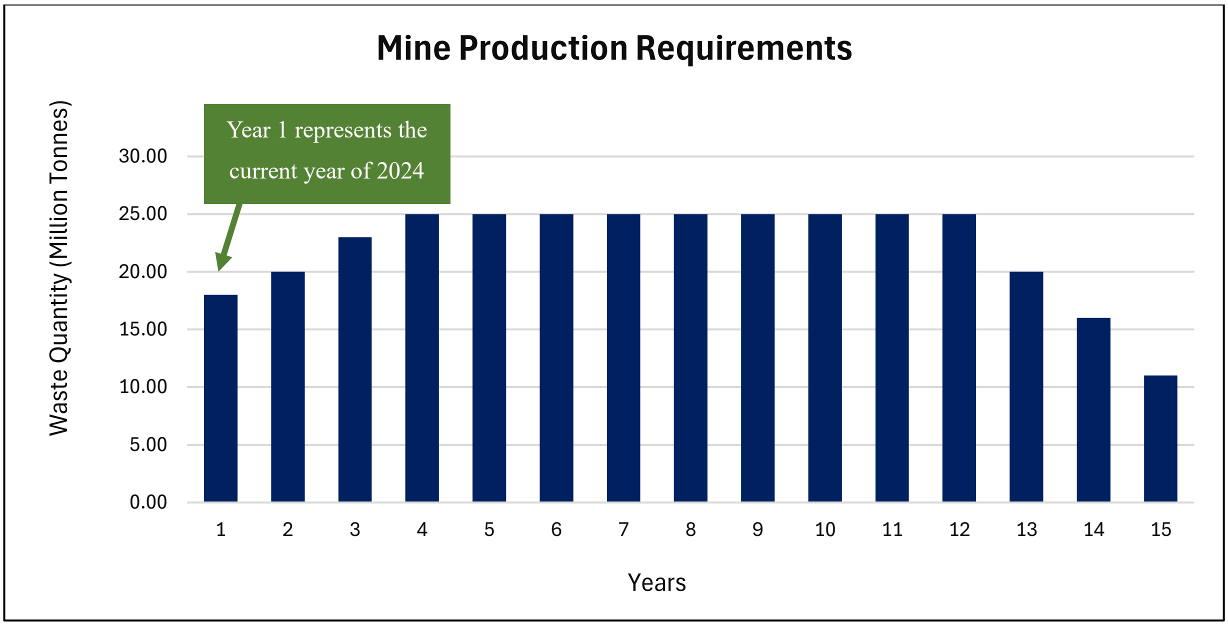

Figure 2: Waste Production over the Life of the Mine (Compiled by Author from data from the mine under study, 2024)

2.2.2 New Dump Site Considerations

With the planned pit expansion, the mine faces the challenge of establishing a new dumping site to accommodate the surplus waste. This proposed site, located 6 km from the existing pit, represents a logistical challenge due to the resulting 200% increase in hauling distances. This expansion introduces complexities that extend beyond the sheer volume of material moved, impacting operational costs, fuel consumption, and overall efficiency.

2.2.3 Position of the In-pit Crushing and Conveying System

The mine is assessing the feasibility of implementing an IPCC system positioned safely away from the pit footprint. Such a configuration necessitates the adoption of a hybrid approach, combining elements of both the CTS system and IPCC methods. Under this hybrid method, the conventional CTS system would be responsible for transporting waste from the pit to the IPCC system. Subsequently, within the IPCC system, the waste would undergo crushing and then be transferred to the waste dump via a network of conveyor belts. Specifically, the CTS operation would cover a hauling distance of 2km, after which the conveyor belt system within the IPCC framework would take over, transporting the material for the remaining distance.

3 LITERATURE REVIEW

3.1 Waste Management in Open Pit Mines

3.1.1 Haulage Systems Used on Open Pit Mines

Hauling operations in open pit mines play a pivotal role in the transportation of both ore and waste materials, representing a critical phase in the mining process (Kennedy, 1990). This process involves the utilization of loading equipment to transfer blasted rock from the mining face into hauling equipment. Subsequently, the hauling equipment is responsible for transporting the material to its designated destination within the mine. In open pit mines employing IPCC systems, a distinctive approach is taken. Blasted rock is fed into in-pit crushers using loading equipment or dump trucks, and following the crushing process, the material is efficiently transported to its destination through conveyor belts.

Two primary types of equipment commonly serve as the mainstays of hauling operations in open pit mines: dump trucks and conveyor belts (Awuah-Offei et al, 2009). Rigid Dump Trucks (RDTs), characterized by a fixed chassis and a hinged dump box at the rear, are prevalent in the mining industry (Off-Highway Research, 2019). With payload capacities varying widely, RDTs can transport materials over substantial distances, up to 9 km (Bokaba, 2018). The market features giants like Caterpillar 797F and Belaz 75710, boasting payload capacities of 393 tonnes and 450 tonnes, respectively. On the other hand, Articulated Dump Trucks (ADTs) are tractor-trailer vehicles with an articulated frame, offering payload capacities of up to 60 tonnes and excelling in navigating steep gradients and challenging floor conditions (Haddock, 1998).

Conveyor belts, as continuous material handling systems, are integral to open pit mining operations (Awuah-Offei et al, 2009). Extensively utilized in various industries, including cement, chemicals, and mining, these belts operate efficiently within a temperature range of -20 degrees to +40 degrees and can handle materials with temperatures up to 50 degrees (Sheng & Youcai, 2016). The conveyor belt system involves loading material through a feeding chute, with pulleys regulating belt tension and idlers providing support for both the belt and the conveyed material. At the tipping point, the material is discharged through a chute, completing the conveyor belt's role in the seamless and continuous movement of materials within the mining process (Bahadori, 2016).

Understanding the distinct characteristics and capabilities of these hauling equipment components is crucial for optimizing open pit mining operations and ultimately contributing to enhanced efficiency and reduced costs in the mining industry.

3.1.2 Rock Fragmentation

Rock fragmentation plays a pivotal role in the selection of an efficient material handling system within the mining industry. This consideration arises from the necessity for mining equipment to effectively load and transport the diverse sizes of rock fragments generated during the extraction process (Awuah-Offei et al, 2009). Among the various methods employed for rock fragmentation, blasting stands out as the most efficient technique for breaking down large masses of hard rock, marking the initial phase in a mine's production chain dedicated to reducing rock size (Elahi & Hosseini, 2017). This process involves the meticulous drilling of a pattern of holes into the rockmass, loading these holes with explosives, and subsequently igniting the explosives to fracture the rock.

The effectiveness of blasting in achieving the desired rock fragmentation is contingent upon both the geotechnical properties of the rockmass and the blast design implemented. According to Singh et al. (2016), these geotechnical properties are beyond the direct control of the mining operation, underscoring the critical importance of continuously optimizing the blast design to align with the evolving geotechnical conditions encountered during the mining process. Failure to do so could result in the production of rock fragments that are impractically large for efficient handling. In such instances, the implementation of secondary rock breaking techniques becomes necessary to further reduce the size of the rocks. However, the application of these secondary techniques introduces the risk of delays to subsequent operations such as loading, hauling, and crushing, as highlighted by Elahi and Hosseini (2017).

In essence, the interplay between geotechnical properties, blast design, and the subsequent need for secondary rock breaking underscores the complexity of managing rock fragmentation in mining operations. It emphasizes the significance of adopting a holistic and adaptive approach to optimize the entire rock fragmentation process, ensuring the seamless flow of materials throughout the mining production chain. Efficient rock fragmentation not only enhances the productivity of the mining operation but also contributes to minimizing delays and optimizing the overall efficiency of material handling systems (Singh et al, 2016).

3.2 In-Pit Crushing and its Role in Mining Operations

Crushing stands as a crucial step in the mining production chain, occurring as the second or third phase, depending on whether secondary breaking is involved. Its primary purpose is to reduce the size of rock fragments, making them suitable for subsequent processing at the plant (Elahi & Hosseini, 2017). When it comes to the crushing of ROM ore, two primary options exist: crushing at the plant or in the pit. The latter, termed in-pit crushing, involves crushing within the mining pit itself, a concept detailed by Metso (2019) and MMD (2016).

3.2.1 Types of In-Pit Crushing and Conveying Systems

In the realm of IPCC systems, three distinct types emerge: fixed, semi-mobile, and fully mobile systems. The Fixed IPCC (FIPCC) system represents a foundational approach where loading units, such as mining shovels or wheel loaders, are employed to load fragmented ROM material directly at the mining face into dump trucks. These trucks then transport the ROM material to the strategically located in-pit crusher, typically situated at the crest of the pit. A defining characteristic of the fixed system is the stationary position of the in-pit crusher, which operates without relocation for an extended period, often exceeding five years (Nehring et al, 2018). This stability offers predictability and long-term planning benefits, allowing mining operations to optimize their material handling processes over an extended timeframe.

The Semi-Mobile IPCC (SMIPCC) system operates on a similar premise to the FIPCC system, with loading units transferring fragmented material to an in-pit crusher. However, the key distinction lies in the relocation frequency of the in-pit crusher. As elucidated by Nehring et al (2018), in the SMIPCC system, the crusher is relocated as frequently as needed, typically every two to five benches. This strategic mobility is designed to maintain a short hauling distance, optimizing operational efficiency and ensuring that the system remains responsive to evolving mining conditions. The semi-mobile nature of this system strikes a balance between the stability of the fixed system and the dynamic adaptability required in the ever-changing mining environment.

The Fully Mobile IPCC (FMIPCC) system represents a paradigm shift in material handling, eliminating the need for dump trucks altogether. Loading units are employed to directly feed fragmented rock into the in-pit crusher. The defining feature of the FMIPCC system is its complete mobility, as it seamlessly follows the loading unit throughout the mining operation (Nehring et al, 2018). This eradication of dump trucks from the equation reduces operational complexities and enhances efficiency, aligning with the industry's pursuit of streamlined processes and reduced environmental impact.

3.2.2 Research on the Adoption of IPCC Systems

Hashemi et al (2011) conducted a comprehensive review of the IPCC system, providing a detailed insight into its operations, advantages, and disadvantages. Their work delved into the intricate details of conveyor belts used in this system, highlighting the diversity of options available. Understanding the nuances of conveyor belt choices is crucial, as it directly influences the efficiency and reliability of the entire IPCC process. The study serves as a foundational resource for mining professionals seeking to optimize their material handling strategies by making informed decisions about equipment and technologies.

Building on this foundation, Dzakpata et al (2016) undertook a comparative analysis, pitting a CTS system against an IPCC system in terms of operating time. The magnitude of their dataset, encompassing 308,912 load records and 12 months of equipment usage, provided a robust basis for evaluation. The findings revealed a substantial 25% increase in operating hours for the IPCC system compared to the traditional truck and shovel system. This data-driven evidence underscores the operational efficiency gains achievable through the adoption of IPCC systems, making a compelling case for their integration into modern mining practices.

Paricheh et al (2017) expanded the research landscape by investigating the strategic placement of in-pit crushers within mining operations. Their work addressed the practical challenges faced by mines employing both traditional and continuous material systems. When the hauling distance for dump trucks becomes economically unviable, the need for in-pit crushers to relocate arises. To navigate this complex decision-making process, the researchers developed a mathematical model. This model considered critical parameters, including hauling distances between mining faces and tipping areas, as well as crusher relocation costs.

The real-world applicability of this model was demonstrated through a case study at the Sungun copper mine in Iran, showcasing its potential to inform decision-making and enhance the economic viability of mining operations (Paricheh et al, 2017).

In the pursuit of sustainable mining practices, Soofastaei & Knights (2018) shifted the focus to energy efficiency within loading and hauling operations. Motivated by the global movement away from fossil fuels, their research analyzed various mining equipment types, including mining shovels, dump trucks, and IPCC systems. The findings revealed a substantial energy footprint associated with fuel consumption by mining equipment, constituting 40% of the total energy used on surface mines. Crucially, the study demonstrated that traditional loading and hauling systems lag behind IPCC systems in energy efficiency. This was illustrated through the comparison of a 327-tonne truck achieving 38% efficiency against a 5m long conveyor belt achieving an impressive 95% efficiency. Such revelations underscore the pivotal role of IPCC systems in not only optimizing operational hours but also contributing significantly to the broader sustainability goals of the mining industry.

3.3 Financial Considerations in Mining Operations

Ensuring the accurate evaluation of the financial viability of projects is paramount for making sound investment decisions, constituting a crucial element in the overall success of any business. Investment decisions involve committing a substantial amount of capital for an extended period, as highlighted by Correia (2015), and the repercussions of these decisions can reverberate through the financial health of a company. Overlooking the intricacies of financial assessments can lead to detrimental consequences. Over-investing, for instance, poses the risk of incurring unnecessary costs and can result in substantial losses or diminished returns. On the other hand, under-investing may expose a company to the peril of producing inferior products or lacking the capacity to meet market demand, potentially resulting in the loss of valuable market share (Correia, 2015).

To navigate the complexities of investment decisions, companies turn to Capital Budgeting (CB) techniques, which are widely recognized and considered best suited for the thorough analysis and evaluation of potential investments (Correia, 2015). These techniques, as elucidated by Correia (2015), encompass four primary methods: Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and the Accounting Rate of Return (ARR).

These methods are broadly categorized into two groups: Discounted Cash Flow (DCF) and non-Discounted Cash Flow methods. DCF methods, exemplified by NPV and IRR, incorporate the time value of money into their assessments, recognizing the importance of considering the timing of cash flows. On the other hand, non-DCF methods, such as PBP and ARR, do not incorporate this temporal element. The judicious utilization of a combination of these CB techniques empowers companies to conduct comprehensive evaluations of their projects, considering various financial metrics and considerations (Correia, 2012). This multifaceted approach allows businesses to align their investment decisions with their broader financial objectives, minimizing the risks associated with over- or under-investment and fostering sustained success in a competitive business landscape.

3.3.1 Discounted Cash Flow Methods

3.3.1.1 Net Present Value

Net Present Value (NPV) serves as a quantitative measure for evaluating the monetary value of a project, as outlined by Kedige (2016). Oki et al (2018) elaborate on this method, explaining that NPV involves discounting the future cash inflows and outflows of a project to their present value (PV). This calculation, utilizing a discount rate or the cost of capital, determines the net monetary gain or loss associated with the project. The financial viability of a project is typically determined by the sign of its NPV, with a positive NPV indicating feasibility (Rudolph, 1990). When comparing mutually exclusive projects, Rudolph (1990) suggests selecting the one with the highest NPV. NPV is praised for its comprehensiveness and consideration of the time value of money, but it heavily relies on accurately estimating the discount rate (Oki et al, 2018).

3.3.1.2 Internal Rate of Return (IRR)

Internal Rate of Return (IRR), defined by Rudolph (1990) as the effective interest rate of return on invested capital, signifies the average rate of return on employed capital. Correia (2015) characterizes it as the discount rate that equates the present value of net future cash flows to the cost of the investment. According to Rudolph (1990), a project should not be accepted if its IRR is less than the discount rate, as this would result in a negative NPV. Moreover, the IRRs of individual projects cannot be combined to represent a combination of projects (Oki et al, 2018).

The strengths of IRR lie in its consideration of all cash flows throughout the project's life and its incorporation of the time value of money (Imegi & Nwokoye, 2015). However, its limitation lies in the inability to use publicly available information for estimation (Feenstra & Wang, 2000).

Both NPV and IRR stand as indispensable tools in the toolkit of financial evaluation, offering nuanced insights into the feasibility and profitability of investment projects.

3.3.2 Non-Discounted Cash Flow Methods

3.3.2.1 Payback Period

The PBP method serves as a valuable tool in investment evaluation, specifically focusing on determining the time required to recover the initial capital invested in a project. As articulated by Correia (2015), the calculation involves dividing the initial capital investment by the periodic cashflows associated with the project. This straightforward formula provides a clear indication of when the initial investment will be recouped. Authors such as Correia (2015) and Umair (2015) have suggested a nuanced refinement to the PBP method, recognizing the significance of the time value of money. This enhancement involves incorporating discounted cash flows into the PBP calculation, creating what is known as a discounted PBP (Correia, 2015). By considering the discounted nature of cash flows, this modified approach offers a more accurate representation of the actual time required to recover the capital investment, aligning the PBP method with the principles of discounted cash flow analysis.

Acceptability of a project using the PBP method is determined by whether its payback period aligns with or is less than the period deemed acceptable by the company, as highlighted by Umair (2015). In the context of comparing multiple projects, Rudolph (1990) proposes that the project recovering its acquisition costs sooner is considered more profitable, emphasizing the significance of a shorter payback period. One of the main advantages of the PBP method lies in its simplicity and ease of understanding. Acting as a screening tool, it provides a quick assessment of the time required for an investment to become financially self-sufficient. However, as noted by Oki et al (2018), its main disadvantage is its inability to distinguish the origins of cashflows. This limitation means that the PBP method may overlook the composition and source of cash inflows, potentially providing an oversimplified perspective on the investment's financial dynamics.

The PBP method, whether in its traditional form or as a discounted variation, remains a valuable and accessible metric in investment evaluation. While its simplicity makes it an attractive initial assessment tool, its shortcomings emphasize the need for supplementary methods, such as NPV and IRR, to offer a more comprehensive understanding of the financial viability and profitability of investment projects.

3.3.2.2 Accounting Rate of Return

The ARR is a metric that gauges the effectiveness of management in utilizing a company's assets, as defined by Correia (2015). Rooted in the accrual concept of accounting and considered a periodic variable, ARR provides insights into the efficiency of resource utilization within a given timeframe (Feenstra & Wang, 2000). Primarily used as a screening tool, ARR aids in the initial evaluation of investment projects, offering a snapshot of their potential viability (Oki et al., 2018). Correia (2015) outlines the calculation of ARR from a company's financial statements, emphasizing its simplicity and ease of derivation. The average incremental net income represents the anticipated average increase in net income if the project is accepted, calculated by dividing the total net income of the project by its useful life. The average investment is derived by dividing the cost of the investment by two (Correia, 2015).

For a project to be deemed acceptable using the ARR method, its calculated ARR should exceed the rate of return required by the company (Oki et al, 2018). This comparison provides a straightforward criterion for decision-making in investment evaluation. The chief advantage of the ARR method lies in its simplicity and ease of calculation, utilizing readily available data from financial statements. However, Imegi & Nwokoye (2015) point out notable drawbacks. ARR overlooks the impact of working capital on project viability, potentially leading to an incomplete assessment of a project's financial health. Additionally, the method does not factor in the time value of money, an omission that can affect the accuracy of the ARR's conclusions regarding the profitability and feasibility of an investment over time.

While the ARR method offers a quick and accessible means of evaluating investment projects, its limitations underscore the need for a holistic approach in financial decision-making. Combining ARR with other sophisticated metrics, such as NPV and IRR, ensures a more comprehensive and accurate understanding of a project's financial dynamics and long-term viability.

3.3.2.3 Proposed Capital Budgeting Techniques for the Research

In a comprehensive examination of CB practices within the South African context, Correia (2012) conducted a thorough review that spanned the literature from 1972 to 2008. The findings suggested a noteworthy evolution in the utilization of DCF methods over the examined period. The review culminated in an analysis of contemporary practices, drawing data from a survey of 35 companies listed on the Johannesburg Stock Exchange. According to Correia's (2012) study, a substantial 82% of the surveyed companies employed NPV, while 79% utilized IRR. Additionally, 54% of the companies relied on PBP, and 14% opted for ARR. This empirical snapshot revealed a prevalent preference for DCF methods, underscoring the industry's recognition of the importance of considering the time value of money in investment decision-making.

In a parallel investigation specific to the mining sector in South Africa, Kedige (2016) delved into the application of CB techniques in evaluating mining projects. Targeting decision-makers including finance managers and directors of mining companies, Kedige's survey shed light on the prevalent preferences within this industry. The results indicated a substantial 83.3% preference for NPV, affirming its dominance as a favored evaluation metric. Additionally, 61.5% and 58.3% of respondents employed IRR and PBP, respectively, showcasing a consistent reliance on these methods. Interestingly, the survey suggested a lack of preference for ARR in the mining sector (Kedige, 2016).

Building upon the insights garnered from these two studies, the proposed research seeks to leverage a combination of NPV, IRR, and PBP to evaluate the financial viability of implementing the waste IPCC system. This approach aligns with the prevalent practices identified in both the broader business landscape and the specialized mining sector. By incorporating these well-established CB techniques, the proposed research aims to provide a robust and comprehensive evaluation framework, considering both the industry standards and the unique requirements of the waste IPCC system.

3.4 Proposed Conceptual Framework

The proposed conceptual framework for this research is shown in Figure 3. It focuses on waste management in open pit mining, beginning with the haulage systems responsible for transporting waste material from the mining face to its final destination.

Two main systems are used: the CTS and the IPCC system. While CTS relies on trucks to move materials, the IPCC system provides a more integrated and potentially efficient method by crushing and conveying materials directly from the pit. The effectiveness of rock fragmentation is crucial in selecting the most efficient material handling system, as it impacts the ability of mining equipment to load and transport the various sizes of fragmented rock (Awuah-Offei et al, 2009).

The choice between CTS and IPCC systems is driven by a financial evaluation. This assessment involves a detailed comparison of the capex and opex of each system, alongside financial performance indicators such as NPV, IRR, and the PBP. These financial metrics provide insights into the long-term viability and profitability of each system, helping to determine which haulage approach offers the best balance between cost efficiency and operational performance for a mining operation.

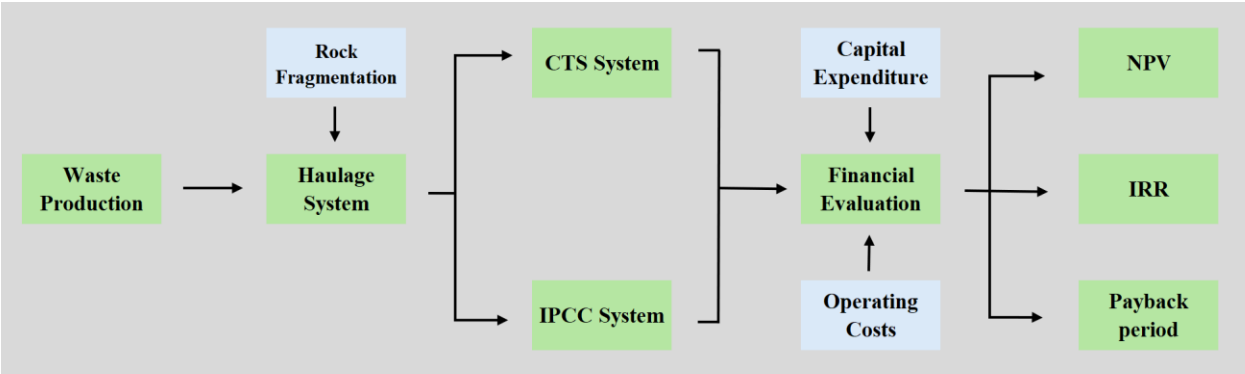

Figure 3: Proposed Conceptual Framework

4 METHODOLOGY

4.1 Research Design

4.1.1 Research Context

The study is contextualized within the operational environment of an open pit mine currently utilizing CTS methods for waste management. The research compares the financial implications of transitioning to IPCC systems, considering various productivity and cost factors and expert opinions.

4.1.2 Research Approach

This research adopted a mixed-methods approach, integrating both quantitative and qualitative data. Wisdom & Creswell (2013) suggest that this combination allows for a more comprehensive and synergistic utilization of data. FoodRisC (2016) emphasized that integrating these methods enables researchers to achieve a deeper understanding of the addressed problem. According to Walwyn (2017), blending these methodologies enables researchers to enrich the conclusions drawn from quantitative data with qualitative insights. Quantitative data was derived from production records, operating costs, equipment performance indicators, and capital expenditures, while qualitative insights were gathered through expert interviews.

4.2 Data Collection Methods

4.2.1 Quantitative Data

4.2.1.1 Production Data

The study involved a diligent process of equipment selection and size matching to ascertain the necessary primary and support equipment for each waste management method to align with the mine's production targets. These production targets were acquired from the mine's planning department.

Concerning the CTS system, the research drew upon historical production data from a representative open pit mine employing these methods.

This dataset encompassed crucial parameters, including production rates, operating times, cycle times, and the mechanical availability and utilization of mining equipment. This data acquisition was crucial as it delineates the prevailing local conditions in which the open pit operates.

For the IPCC system, a comprehensive set of production data was gathered from Original Equipment Manufacturer (OEM) sources. This information played a vital role in calculating the necessary type, size, and quantity of equipment required to meet the production demands of the mine.

4.2.1.2 Operating Costs

Data on operating costs, encompassing current maintenance expenses, fuel expenditures, and labor outlays, were derived directly from the financial records of the mine under study. Correspondingly, the operational costs for IPCC systems were sourced directly from the OEM. The compilation of these cost metrics was imperative for calculating the operational outlays linked to each waste management approach.

4.2.1.3 Capital Expenditures

Capital expenditure (CAPEX) information pertaining to truck and shovel equipment was acquired through collaboration with OEMs. In a parallel effort, the capital costs associated with IPCC systems were diligently gathered from OEMs with expertise in the development and implementation of these advanced technologies. This comprehensive approach ensured the incorporation of precise and up-to-date data, facilitating a thorough examination of the investment requirements for both traditional and innovative waste management methodologies.

4.2.2 Qualitative Data

4.2.2.1 Expert Interviews

Structured interviews with industry experts were to collect qualitative insights on IPCC systems. The primary goal of these interviews was to capture expert opinions regarding the advantages, challenges, and future prospects associated with the implementation of IPCC systems for waste management in open-pit mines. The participants in these interviews were meticulously chosen individuals with notable expertise in both open-pit mining practices and IPCC technologies.

The identification of these subject matter experts was facilitated through the widely used LinkedIn online platform, ensuring a diverse and knowledgeable pool of participants with substantial experience in the pertinent fields. Only a single expert was interviewed as none of the identified experts expressed interest in participating in the research.

4.3 Data Analysis

4.3.1 Comparative Cost Analysis

A detailed cost comparison was executed, comprehensively covering both capital and operating expenses associated with traditional truck and shovel methods as well as IPCC systems. This comprehensive assessment encompassed a meticulous examination of various cost components, including those linked to equipment procurement, maintenance, fuel, labor, and any other pertinent expenses intrinsic to each waste management system.

In exploring the capital expenses, the study delved into the costs related to acquiring and replacing equipment, considering figures obtained from OEMs for both traditional and IPCC technologies. Operating expenses, on the other hand, were thoroughly scrutinized, accounting for ongoing costs such as maintenance, fuel consumption, and labor expenditures. The inclusion of additional relevant expenses specific to each waste management method aimed to capture a holistic representation of the financial implications associated with the adoption of either traditional truck and shovel methods or IPCC systems.

This nuanced cost comparison was pivotal in providing a comprehensive understanding of the economic landscape, enabling stakeholders to make informed decisions based on a thorough assessment of the financial considerations associated with each waste management approach.

4.3.2 Financial Evaluation

The financial evaluation compared the NPV, IRR, and Payback Period for traditional truck and shovel methods and IPCC systems. This analytical approach aimed to provide a comprehensive understanding of the economic feasibility, and long-term financial implications associated with adopting IPCC systems for waste management in open-pit mining.

The research scrutinized NPV, IRR, and Payback Period metrics, serving as critical benchmarks for comparing the present value of cash flows, internal rate of return on investments, and time required to recoup initial investments. Through this comprehensive examination, valuable insights were offered into the comparative financial performance of traditional and IPCC waste management systems, assisting stakeholders in making informed decisions about the most economically advantageous approach for their mining operations.

4.3.3 Sensitivity Analysis

To account for uncertainties, a sensitivity analysis was conducted. This involved varying key parameters critical to the economic assessment, including commodity prices, operating costs, and equipment performance. The purpose of this analytical endeavor was to systematically gauge the resilience of the financial evaluation model across a spectrum of scenarios. By subjecting the model to fluctuations in these pivotal variables, the study sought to identify how changes in commodity prices, operating costs, and equipment performance could impact the overall financial viability of implementing IPCC systems compared to traditional waste management methods.

4.3.4 Content Analysis

The data extracted from the structured interview underwent a meticulous analysis utilizing content analysis techniques. This analytical approach enabled a systematic examination of the interview responses, allowing for the identification and categorization of key themes, patterns, and nuances expressed by the expert. The amalgamation of these qualitative insights with quantitative data formed a comprehensive basis for a nuanced understanding of the perspectives on IPCC systems within the context of waste management in open-pit mines.

4.4 Flowchart for the Research Process

The flowchart shown on Figure 4 represents the research process used in this study. The key components outlined in the flowchart are described below:

Data Collection (Input)

- Quantitative Data:
  - Production Data: Historical data and OEM sources provide production rates, cycle times, and equipment utilization.
  - Operating Costs: Financial records of the mine (for truck and shovel) and OEM data (for IPCC systems) give insights into maintenance, fuel, and labour costs.
  - Capital Expenditures: Collaboration with OEMs to gather capital expenditure data for both systems.
- Qualitative Data:
  - Expert Interviews: Collect qualitative insights from an expert on the advantages and challenges of IPCC systems.

Data Analysis (Process)

- Comparative Cost Analysis: Use production data, operating costs, and capital expenditure to compare financial costs of the CTS system with the IPCC system.
- Financial Evaluation: Analyze NPV, IRR, and payback period based on the comparative cost analysis, determining economic feasibility.
- Sensitivity Analysis: Vary key parameters (commodity prices, operating costs, equipment performance) to test the robustness of the financial models for both waste management methods.
- Content Analysis: Use insights from the expert interview to enrich the qualitative understanding of IPCC systems and complement the financial analysis.

Final Output

- Comprehensive Evaluation: By combining quantitative data and qualitative insights, the research provides a thorough comparison of CTS and IPCC systems in terms of cost, financial performance, and practical viability, enabling informed decision-making.

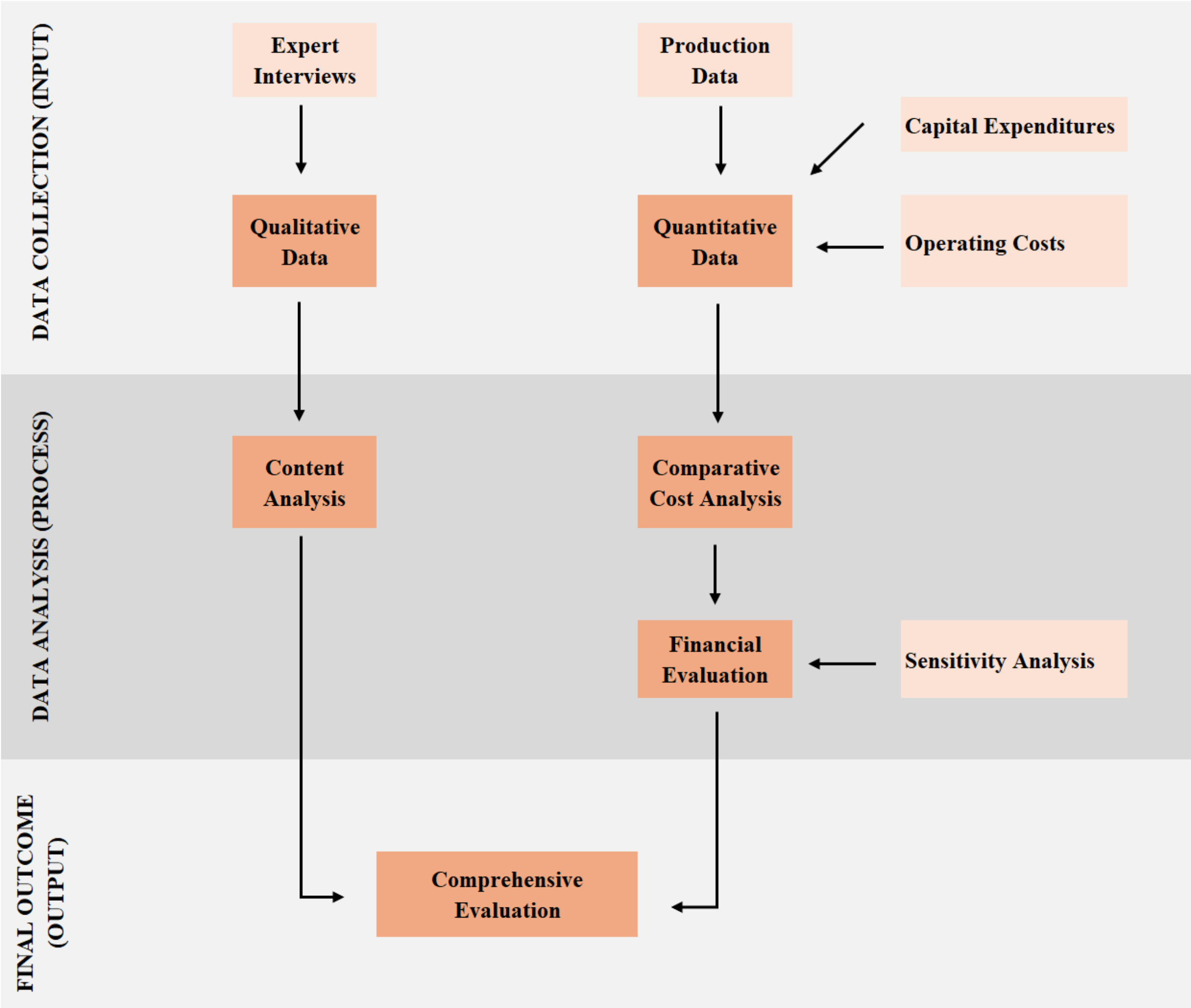

Figure 4: Flowchart for the Research Process used in this Study

5 QUANTITATIVE RESULTS

The quantitative findings of the research are outlined in the following subsections.

5.1 Equipment Requirements

A thorough equipment selection process was conducted to identify the machinery needed to meet the production needs of the mine under each haulage method. This involved assessing the ideal types, sizes, and quantities of equipment essential for smooth operations. Table 1 illustrates the equipment for conventional truck and shovel operations, while Table 2 showcases the equipment for IPCC operations.

Table 1: Equipment Requirements for Conventional Truck and Shovel Systems

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Large loader	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2
Small loader	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Pecker	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Track dozer	8	8	8	10	10	10	10	10	10	10	10	10	8	6	6
Rigid dump truck	40	44	51	55	55	55	55	55	55	55	55	55	44	35	24
ADT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wheel dozer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wheel loader	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grader	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3
Water bowser	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2
Diesel bowser	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2
Lubrication truck	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2

Table 2: Equipment Requirements for In-pit Crushing and Conveying Systems

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Large loader	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2
Small loader	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Pecker	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Track dozer	8	8	8	10	10	10	10	10	10	10	10	10	8	6	6
Rigid dump truck	22	25	28	31	31	31	31	31	31	31	31	31	25	20	14
ADT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wheel dozer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wheel loader	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grader	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2
Water bowser	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2
Diesel bowser	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
Lubrication truck	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
Conveyor system	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crusher system	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 Cost Analysis of Implementing IPCC vs Conventional Truck and Shovel Systems

The decision to implement IPCC systems over CTS operations in mining brings forth a complex array of considerations, prominently centered around the financial landscape. As industries evolve towards more sustainable and efficient practices, open-pit mines are increasingly exploring alternatives to traditional mining methodologies. This study delves into the intricate web of costs associated with implementing IPCC systems compared to the well-established truck and shovel systems, offering a perspective on the economic implications.

At the forefront of this analysis is the examination of initial CAPEX, a pivotal factor that significantly influences the feasibility and decision-making process for mining operations. Understanding these upfront costs provides a foundational insight into the economic dynamics of each system. Moving beyond the inception stage, the exploration of operating and maintenance costs further enriches the understanding of the long-term financial commitments associated with both mining methodologies. By comprehensively dissecting these various cost dimensions, this analysis aims to equip decision-makers with a holistic understanding of the financial implications, aiding in the strategic choice between IPCC and CTS systems in open-pit mining.

5.2.1 Initial Capital Costs

Table 3 and Figure 5 illustrate a comparison of the initial costs associated with implementing IPCC and CTS systems. Notably, RDTs constitute 57% and 29% of the initial CAPEX for the CTS and IPCC systems, respectively. It's worth noting that "other" encompasses support equipment such as water bowsers, dozers and graders.

Table 3: Comparative Analysis of Initial Capital Costs

System	Cost (R billion)
IPCC	1.37
CTS	1.26

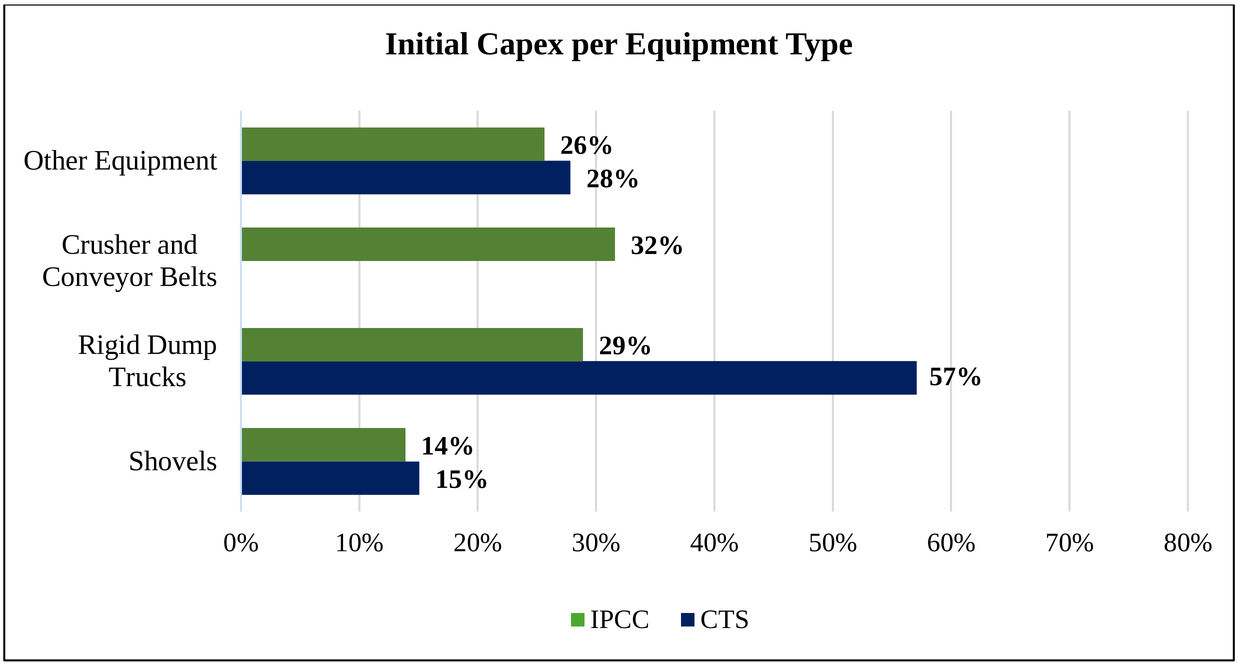

Figure 5: Initial CAPEX per Equipment Type

5.2.2 Stay-in-Business Capital Costs

As mine production increases from 18 million tonnes to 25 million tonnes (see Figure 2), the acquisition of additional equipment will be necessary. Furthermore, as the equipment ages, replacement will become essential. The costs linked to this are presented in the tables below for each system. It's crucial to emphasize that, as stated in sub-section 1.7, it was assumed that the crusher and conveyor belt system of the IPCC system would not require replacement throughout the 15-year mine lifespan. Consequently, replacements are determined based on the loading and hauling mining fleet and their accompanying support equipment. The SIB costs were projected at R692 million for the CTS system and R547 million for the IPCC system.

5.2.3 Operational Costs

Table 4 outlines the operating costs for each system over the mine life of 15 years. The IPCC system is forecasted to have operational expenses totaling R32.6 billion, whereas CTS operations amount to a lower cost of R20.6 billion. Figure 6 and Figure 7 illustrate the breakdown of these costs across various mining activities. It's worth noting that "other" encompasses support activities.

Table 4: Comparative Analysis of Operational Costs

System	Cost (R billion)
IPCC	32.60
CTS	20.59

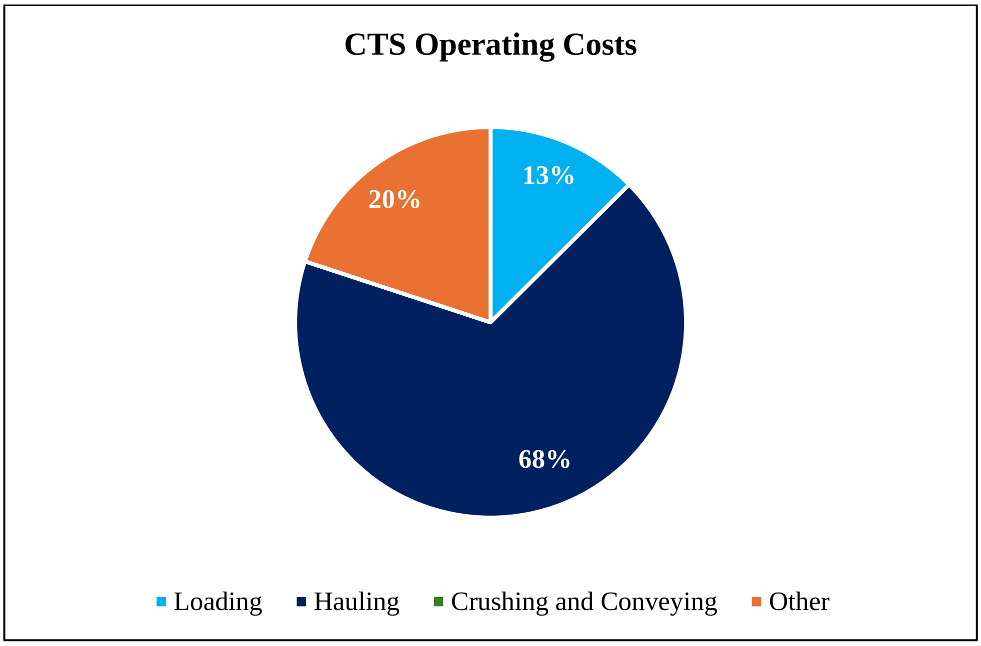

Figure 6: CTS Operating Costs over the Life of the Mine

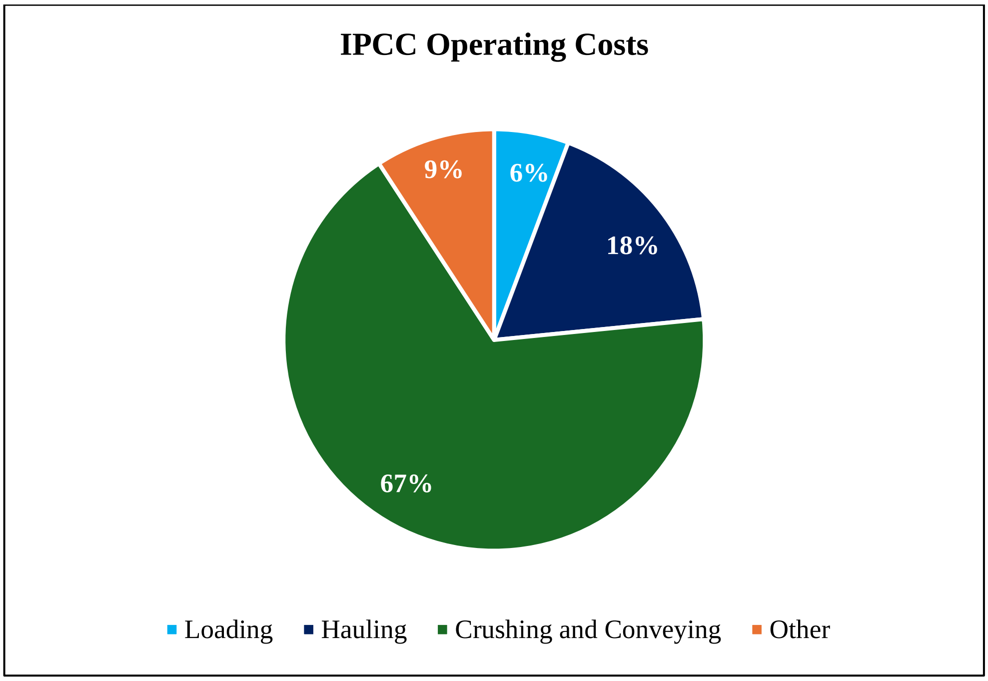

Figure 7: IPCC Operating Costs over the Life of the Mine

5.3 Financial Evaluation

Below is a tabulated comparison of the NPV, IRR, and PBP for each system. The cash flows utilized in the financial assessment were established following the principles outlined in sub-section 3.3 of this report. The gross revenue was computed by considering the annual mining and sale of 2 million tonnes of ore. The net revenue was derived by deducting total mining expenses from the gross revenue. These total expenses encompassed the operational costs of each system under scrutiny, along with other mining expenditures such as drilling, blasting, ore processing, and logistics. Subsequently, a discount rate of 17.2% was applied to discount the cash flows. According to the analysis, the CTS system demonstrates superior financial performance compared to the IPCC system, as indicated by higher NPV, IRR, and a shorter PBP.

Table 5: Comparison of Financial Performance

		CTS	**IPCC**
NPV	R billion	7.45	4.56
IRR		83.1%	49.7%
PBP	Years	1.21	1.99

5.4 Sensitivity Analysis

A sensitivity analysis was performed by adjusting commodity prices and OPEX in 5% increments to evaluate their impact on the financial performance of each haulage system. The analysis examines key financial indicators such as NPV and IRR, presented in Figure 8 for commodity price variations and Figure 9 for OPEX variations. These graphs illustrate the sensitivity of both the IPCC and CTS systems to changing economic conditions, highlighting how financial performance shifts under different price and cost scenarios.

It is important to highlight that IRR is reported as zero when all cash flows are negative. As Belyadi et al (2019) explains, the IRR method assumes at least one positive cash flow in the series to indicate a potential return on investment. When there are no positive cash flows, the IRR calculation becomes mathematically infeasible, as the project cannot yield a return under such conditions.

The payback periods for each system were calculated under the same varying conditions. These results are presented in Table 6 for commodity price adjustments and Table 7 for OPEX variations. The tables provide insight into how quickly each system can recover its initial capital investment under different financial assumptions, contributing to the overall assessment of their viability.

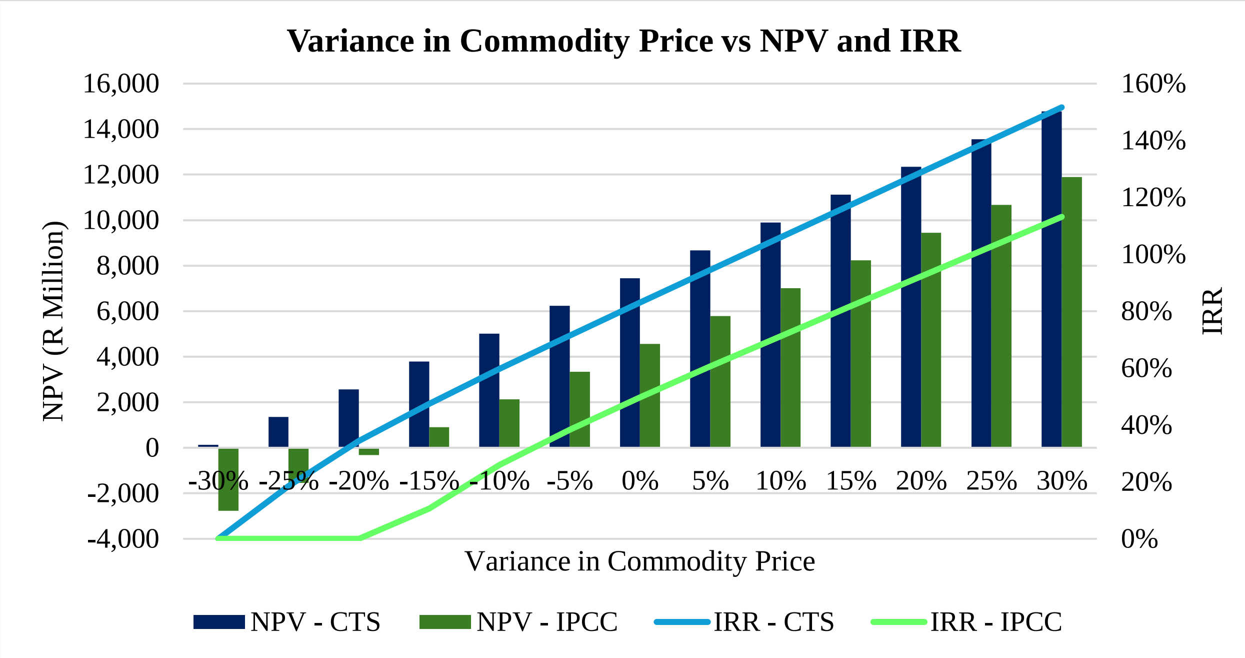

Figure 8: Variance in Commodity Prices vs NPV and IRR

Table 6: Payback Periods for Commodity Price Variations

Variance in Commodity Price	PBP - CTS	PBP - IPCC
-30%	-8.82	-0.88
-25%	7.38	-1.53
-20%	3.02	-3.37
-15%	2.04	-39.33
-10%	1.61	5.32
-5%	1.37	2.77
0%	1.21	1.99
5%	1.11	1.61
10%	1.03	1.38
15%	0.97	1.23
20%	0.92	1.13
25%	0.88	1.05
30%	0.85	0.99

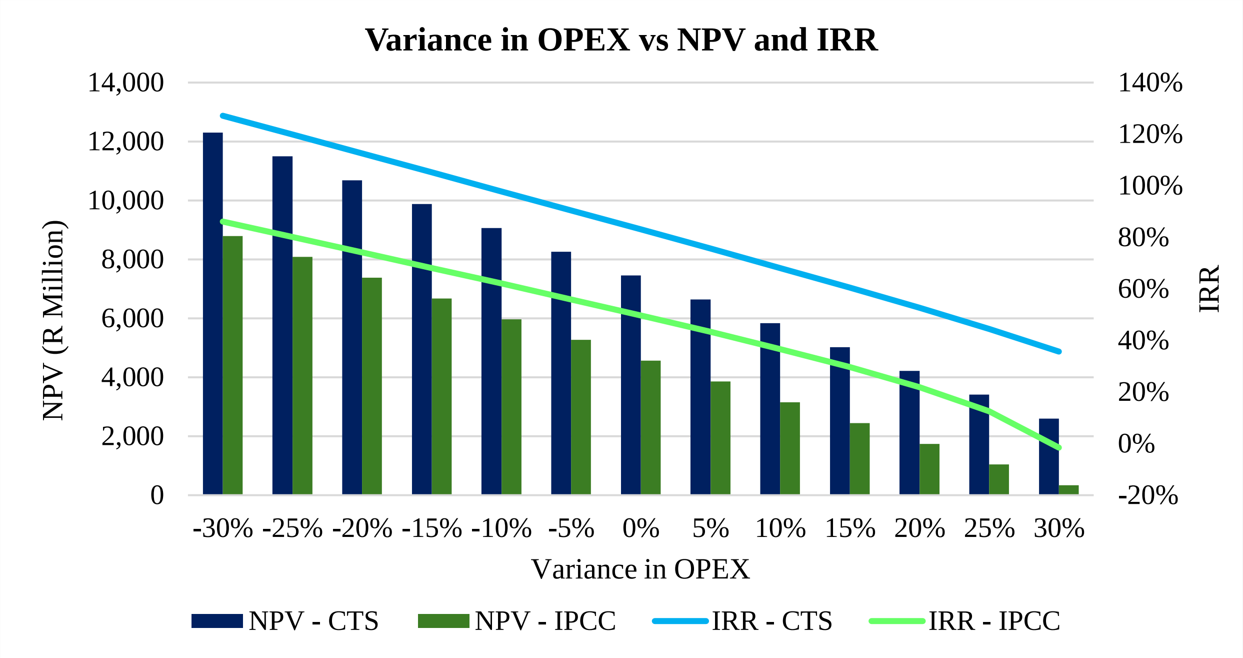

Figure 9: Variance in OPEX vs NPV and IRR

Table 7: Payback Periods for OPEX Variations

Variance in OPEX	PBP - CTS	PBP - IPCC
-30%	0.93	1.19
-25%	0.96	1.25
-20%	0.99	1.33
-15%	1.03	1.44
-10%	1.08	1.57
-5%	1.14	1.74
0%	**1.21**	**1.99**
5%	1.31	2.36
10%	1.43	2.97
15%	1.59	4.19
20%	1.83	7.85
25%	2.19	9.94
30%	2.85	-6.91

6 QUANTITATIVE RESULTS AND ANALYSIS

23 experts were invited to participate in the research and only one showed interest. The interviewee is an experienced professional in the mining sector, with seven years of practical expertise primarily focused on open pit mining operations. However, it is important to note that the interviewee lacks firsthand experience with IPCC technologies. Consequently, their input was not considered in the analysis.

7 DISCUSSION

7.1 Analysis of Research Results

The CTS system relies on RDTs to transport materials to the waste dump, covering a hauling distance of 6km. At steady-state mine production, this entails the operation of 55 RDTs along with various other supporting equipment. As depicted in Figure 5, this configuration carries significant financial implications, with RDTs constituting 57% of the initial capital expenditure. Conversely, the implementation of the IPCC system, positioned adjacent to the pit as detailed in sub-section 2.2.3, positively impacts the hauling distance and consequently reduces the number of trucks and support equipment required. However, despite this improvement, the initial capital expenditure for the IPCC system is higher due to the substantial costs associated with establishing crushers and conveyor belts necessary for transporting materials to the waste dumps. As indicated in Figure 5, the crusher and conveyor belt system account for 32% of the IPCC system's initial capital expenditure.

Upon examining the operating costs over the mine's lifespan, it becomes apparent that there are no cost advantages associated with operating an IPCC system compared to the CTS system. The operating expenses for the IPCC system exceed those of the CTS system by 57%, primarily driven by the operational costs of the crusher and belt system, which contribute to 67% of the IPCC system's costs.

A comprehensive financial evaluation was conducted, considering the total costs of the mine over its 15-year lifespan. Using a discount rate of 17.2%, both systems exhibit positive and acceptable NPVs, as well as acceptable IRRs and PBPs. However, it is evident that the IPCC system demonstrates inferior financial performance when compared to the CTS system. This outcome underscores that the CTS remains a viable option, particularly for hauling distances of 6km.

The sensitivity analysis shows that both commodity prices and OPEX have significant impacts on the financial performance of both the CTS and IPCC systems. Commodity price variations directly influenced NPV and IRR, with higher prices improving financial viability for both systems. Conversely, lower prices negatively affected financial metrics.

Similarly, OPEX fluctuations demonstrated an inverse relationship with financial outcomes. Higher operating costs decreased NPV and IRR, while lower costs improved them. Throughout these variations, the CTS system showed greater financial resilience, affirming its stronger economic viability for the mine study compared to the IPCC system.

7.2 Benefits and Risks

7.2.1 Advantages of IPCC Systems over Conventional Truck and Shovel Methods

The adoption of IPCC systems for waste transport in open-pit mining offers a multitude of benefits, ranging from operational efficiency and safety improvements to environmental sustainability and enhanced ore recovery. These advantages collectively contribute to a more resilient, cost-effective, and socially responsible approach to waste management in mining operations.

7.2.1.1 Reduced Environmental Impact

IPCC systems contribute to a significant reduction in environmental impact compared to conventional truck and shovel systems. The elimination of constant truck traffic reduces air pollution, noise levels, and overall disturbance to the ecosystem surrounding the open pit. In traditional truck and shovel systems, each haul truck emits pollutants, and their movement disturbs the natural habitat. On the contrary, IPCC systems streamline the transport process, minimizing the ecological footprint and preserving the environmental balance of the area. Additionally, the reduced need for extensive road networks decreases the disturbance to the local flora and fauna, promoting a more sustainable and ecologically friendly waste transport method.

7.2.1.2 Minimized Infrastructure Requirements

Compared to the extensive infrastructure needed for truck and shovel systems, IPCC systems often require less infrastructure for waste transport. The elimination of long-distance haul roads and associated maintenance reduces the capital and operational expenses related to infrastructure development. This benefit is particularly significant in remote or challenging terrains where constructing and maintaining extensive road networks can be logistically complex and financially burdensome. IPCC systems provide a more economical and resource-efficient solution, streamlining waste transport without compromising operational effectiveness.

7.2.2 Risks and Mitigation Strategies

7.2.2.1 Operational Complexity and Maintenance Challenges

While IPCC systems offer operational efficiency, the complexity of their design and integration within the open-pit environment poses challenges in terms of maintenance and system reliability. Mitigating this risk involves implementing robust maintenance protocols and predictive analytics to detect potential issues before they escalate. Regular inspections, proactive repairs, and comprehensive training for maintenance personnel are essential elements of a mitigation strategy to ensure the sustained performance of IPCC systems. Additionally, having a well-defined contingency plan and readily available spare parts inventory can minimize downtime in case of unexpected failures. Collaborative partnerships with equipment manufacturers for ongoing support and technical assistance further enhance the reliability and longevity of IPCC systems.

7.2.2.2 Environmental Impact and Habitat Disruption

The reduced environmental impact associated with IPCC systems can still pose risks, particularly if not properly managed. The integration of primary crushing within the pit may disturb local ecosystems and habitats. Effective mitigation involves conducting thorough environmental impact assessments before implementing IPCC systems and designing comprehensive rehabilitation plans. Employing advanced dust suppression systems, noise reduction technologies, and erosion control measures can further minimize the environmental footprint. Engaging with environmental regulators, local communities, and environmental advocacy groups in transparent communication fosters understanding and support for the mitigation strategies, ensuring that the benefits of reduced environmental impact are realized without compromising ecological integrity.

7.2.2.3 Material Handling Challenges

The continuous material flow of IPCC systems, while advantageous, introduces challenges related to material handling and potential ore losses. Mitigating these risks involves implementing advanced sorting and screening technologies to ensure that no valuable material reaches the waste dump. Regular training for operators and optimizing material flow through strategic pit planning contribute to minimizing ore loss. Investing in smart sensors and automation technologies enhances precision in material handling, reducing the risk of discarding ore with waste.

7.2.2.4 Adaptation to Pit Geometry and Changing Mining Conditions

The flexibility and adaptability of IPCC systems are essential benefits, but they also present challenges in terms of adapting to evolving pit geometries and changing mining conditions. Effective risk mitigation involves continuous monitoring of pit configurations, employing real-time data analytics, and investing in equipment with modular designs that can be easily reconfigured. Regular geological surveys and pit planning reviews contribute to proactive decision-making, ensuring that the IPCC system remains aligned with the dynamic nature of the mining operation. Collaborating with mining engineers and technology experts allows for ongoing optimization of the IPCC system, minimizing the risk of inefficiencies resulting from changes in pit geometry.

7.2.2.5 Human Capital Challenges and Training Needs

The transition to IPCC systems may require a shift in skill sets for mining personnel, introducing human capital challenges and training needs. Mitigating this risk involves investing in comprehensive training programs to upskill existing staff and attract new talent with the necessary expertise. Collaborating with educational institutions and industry associations to develop training modules specific to IPCC technology fosters a skilled workforce. Implementing a phased approach to technology adoption allows for gradual skill development and minimizes disruptions to ongoing operations during the learning curve.

7.2.2.6 Supply Chain Disruptions and Equipment Availability

The reliance on specialized equipment for IPCC systems exposes operations to supply chain disruptions and potential delays in equipment availability. Mitigation involves diversifying suppliers, maintaining strategic inventories of critical components, and establishing contingency plans for alternative sources. Developing strong partnerships with equipment manufacturers and suppliers can provide access to priority support and expedited delivery in case of unexpected equipment failures. Regularly assessing and updating supply chain risk management strategies ensures resilience in the face of evolving market dynamics.

8 CONCLUSION AND RECOMMENDATIONS

The primary objective of this research was to assess the integration of an IPCC system within the loading and hauling operations of an open pit mine. This objective was effectively achieved, indicating that although the IPCC system could be integrated, some degree of reliance on the CTS system remained necessary for material transportation from the pit to the IPCC system. Furthermore, this evaluation delved into the practical aspects of implementing the IPCC system, considering its positioning and weighing the associated benefits and risks. The secondary objective of the research was to evaluate the financial viability of adopting an IPCC system for waste management. A comprehensive financial analysis was undertaken, revealing that the CTS system exhibits superior financial performance compared to the IPCC system.

In addition to the superior financial performance of the CTS system, another significant finding from this research is the impact of hauling distances on the required mining equipment quantity to meet production demands. Positioning the IPCC system near the pit resulted in a notable decrease of 44% in the number of RDTs needed during steady-state production, reducing from 55 to 31. Despite this substantial reduction in RDTs required for the IPCC system, its operating costs were considerably higher. Thus, from a financial standpoint, the CTS system is recommended for the mine under examination. However, it's important to note that this recommendation may vary if the limitations of the research are considered. These limitations involve the absence of a congestion study to assess the safety and operational efficiency impact of mining fleet required to meet production requirements. Moreover, insufficient consideration of environmental and community concerns in the research, which may affect the financial implications and feasibility of implementing an IPCC system. Additionally, the limited participation in interviews deprived the study of valuable insights that could have enhanced understanding of industry perceptions regarding the system.

Recommendations for future studies include:

- Performing a congestion study to assess the safety implications and overall operational efficiency of the mine as mining equipment demands escalate with rising production and hauling distances.
- Conducting interviews to gather industry perspectives on the implementation of IPCC systems in open pit mines.

- Exploring the correlation between IPCC waste management in open-pit and underground mines; and
- Delving into the detailed assessment of environmental costs and their impact on the financial viability of implementing an IPCC system.

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10 APPENDICES

This section offers select information utilized in the financial assessment. For confidentiality reasons, only approved data is presented.

Appendix A: Operating Costs over the Life of the Mine

CTS Operating Costs over the Life of the Mine	**Cost (R million)**	**Split**
Loading	2 582	13%
Hauling	13 902	68%
Crushing and conveying	0	0%
Other	4 105	20%
Total	**20 589**	**100%**

IPCC Operating Costs over the Life of the Mine	**Cost (R million)**	**Split**
Loading	1 866	6%
Hauling	5 769	18%
Crushing and conveying	21 968	67%
Other	3 000	9%
Total	**32 603**	**100%**

Appendix B: Cashflows over the Life of the Mine

Cashflow		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
CTS Operations	R million	-1 263	903	771	1 070	1 886	1 909	1 840	1 793	1 728	1 615	1 575	1 658	1 639	1 869	1 642	1 599
IPCC Operations	R million	-1 372	513	356	527	1 259	1 279	1 202	1 149	1 078	957	911	986	961	1 323	1 191	1 302

Appendix C: Results of the Financial Evaluation

Results of Financial Evaluation		**CTS**	**IPCC**
NPV	R million	7 452	4 563
IRR		83.05%	49.70%
PB	Years	1.21	1.99