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Strategic Integration of Real Options for Enhanced Valuation and Optimization in Mining Project Planning under Uncertainty: A Comprehensive Review

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Abstract

Purpose: In the contemporary landscape of mining projects, the imperative to navigate through periods of uncertainty has driven the exploration of alternative strategic tools rooted in project flexibility. Real options have emerged as a pivotal strategic approach, offering the means to adapt and refine mining projects under unpredictable conditions

Materials and Methods: This paper provides a comprehensive review and discussion on the strategic application of real options for optimizing mining project planning in the face of uncertainty. Organized into four sections, the paper begins with a general introduction to real options in Section one, delving into their strategic and technical classifications. Section two critically examines and reviews the indispensable role of real options in the realms of mining investment and project planning. The third section is dedicated to an in-depth discussion of the strategic tools inherent in real options, specifically focusing on their valuation and optimization aspects within mining project planning. The final section provides a discussion and conclusion on the strategic application of real options for optimizing mining project planning under uncertainty.

Findings: The review identifies that real options offer valuable strategic flexibility in addressing uncertainties inherent in mining project planning. Through a detailed examination of their application, it becomes evident that real options can enhance decision-making processes and improve project outcomes by allowing for adaptive responses to changing conditions.

Implications to Theory, Practice, and Policy: The strategic integration of real options into mining project planning presents significant implications for theory, practice, and policy. Theoretical implications include advancing understanding of decision-making under uncertainty and the role of flexibility in strategic planning. In practice, the adoption of real options can lead to improved project outcomes, increased resilience to market fluctuations, and enhanced risk management strategies. From a policy perspective, recognizing the value of real options may inform regulatory frameworks and promote the adoption of flexible planning approaches within the mining industry, ultimately contributing to sustainable development and resource management.

Keyword: *Mining, Project Evaluation, Real Options, Planning Models, Project Analysis, Uncertainty*

1.0 INTRODUCTION

Mine planning is a complex undertaking, marked by the intricate interplay of various variables and the nuanced challenges faced by small-scale mining enterprises. Navigating this terrain involves not only the anticipation and strategic planning for an unpredictable natural context but also exerting thoughtful foresight. The ramifications of planning reverberate across the entire spectrum of business operations. Company managers seek heightened consistency and stability in forecasting costs and revenue, aiming for greater value for money. Miners and entrepreneurs, in turn, require well-defined strategies and realistic objectives. Effective planners must articulate how business objectives translate into actionable plans (Abdel Sabour et al. 2006; Adelman et al. 1995).

The mining industry finds itself inextricably linked to the reverberations of the current economic crisis stemming from the aftermath of the coronavirus pandemic. This serves as a stark illustration of the pervasive economic uncertainty. In response, mining projects must adopt alternative strategies in their developmental endeavors to persevere during this period of economic flux (Adner et al. , 2004). Real options, encompassing choices such as delaying, reducing, or abandoning a mining project, emerge as pertinent strategies in navigating the current economic landscape. Indeed, these options have the potential to transform economic uncertainty into opportunities. A multitude of mining projects actively employ such real options strategies, particularly in long-term planning, to mitigate financial losses and address geological uncertainties (Ajak et al. , 2018).

The COVID-19 pandemic has unleashed unprecedented challenges for the global mining industry, profoundly affecting production, supply chains, and financial performance. For instance, according to data from the International Council on Mining and Metals (ICMM), the pandemic-induced disruptions led to a significant decline in mineral production across various regions, with some mining operations experiencing temporary shutdowns or reduced output by up to 30% (ICMM, 2020). Furthermore, the abrupt halt in economic activities and disruptions in transportation networks caused a severe strain on mineral supply chains, resulting in delays in shipments and increased logistical costs. The economic fallout from the pandemic also triggered a sharp decline in commodity prices, with the Bloomberg Commodity Index registering a 15% decrease in the first half of 2020 alone (Bloomberg, 2020). Consequently, many mining companies faced mounting financial pressures, forcing them to reassess their project planning and investment strategies considering heightened uncertainty and volatility in the market. These tangible examples underscore the urgent need for mining enterprises to adopt innovative and adaptive approaches, such as the strategic integration of real options, to mitigate risks, enhance resilience, and ensure the long-term sustainability of their operations in the face of unforeseen crises.

This paper systematically reviews and elucidates the application of real options as a strategic framework for optimizing mining project planning under conditions of uncertainty, drawing insights from diverse sources such as textbooks, scientific journals, articles, and relevant websites. The structure of this work is organized into four sections. The first section provides a comprehensive introduction to real options, delving into its strategic and technical classifications. The second section examines the pivotal role of real options in mining investment and project planning. The third section delves into the strategic tools of real options for valuating mining project planning. The fourth section encompasses discussions and conclusions derived from the findings of this research.

In our review paper, we analyze various types of real options relevant to mining projects and investments. This includes options within mining projects, such as deferral, expansion, and abandonment, as well as options on project investments, such as investment, production switching, and production schedule adjustments. Additionally, we explore how flexibility and uncertainty in mining investments are addressed through real options frameworks.

Real Options (RO)

In the realm of business strategy, the Real Options (RO) approach, as elucidated by Liu et al. (2019), serves as a linguistic framework for delineating a business's array of possibilities, effectively mapping the world as a terrain of opportunities. Positioned as a technique to rationalize augmented flexibility in the face of uncertainty, the intelligence of the option becomes apparent when dealing with data that evolves over time, particularly in the midst of high ambiguity during decision-making. Any flexibility and unconscious factors inherent in management further underscore the relevance of the real options approach.

Wang and Neufville (2004), offer a definition of real options as engineering choices characterized by flexibility—the capacity to substantially modify a system's design. This flexibility empowers system managers to redirect the trajectory of the business, steering clear of adverse consequences or capitalizing on unforeseen opportunities. As articulated by Matts and Maassen (2007), the real options methodology provides individuals with the means to make optimal decisions within their existing context. Evaluation frameworks, such as the Black & Scholes formula or the alternative binomial price model, have been employed for years as strategic decision-making tools, offering a robust foundation for generating more satisfactory results.

Real Options (RO) Strategic and Technical Classification

Building upon the foundational understanding of Real Options (RO), as outlined by Liu et al. (2019), the strategic and technical classification of RO is a critical facet in navigating the landscape of business opportunities. Ajak et al. (2018) illuminates the nuanced distinction between real options 'in' and 'on' a project, emphasizing the significance of this classification based on the vital and technical application of real options. Recognizing this disparity early on is imperative to avoid confusion and underscore the distinct nature of these two classifications.

Adner and Levinthal (2004) contribute to this discourse by positing that the concept of "on-project" RO should be viewed as harnessing flexibility inherent in ongoing investments. Prior to the commencement of mineral reserve mining, a multitude of distinct sequential options exists. Amidst uncertainty, the ability to craft flexible plans and defer decisions, as compared to other strategic decisions during project planning, adds substantial value.

In tandem, Groeneveld and Topal (2011) shed light on the perspective that RO "in" projects manifest as adaptability within the underlying engineering framework, poised to respond to the objectives of vulnerabilities. For instance, in a scenario of optimal metal price improvement, specific components of the initial mining strategy may be developed with sufficient scalability to facilitate rapid expansion in the project's subsequent phases.

This detailed exploration of the strategic and technical classifications of RO enhances our comprehension of how these options unfold within the intricate tapestry of mining project planning, linking back to the broader theme of augmenting flexibility and optimizing decision-making within the context of economic uncertainty.

The Role of Real Options (RO) in Mining Investment

Continuing our exploration of Real Options (RO) within the intricate domain of mining investment, this section delves into the specific dynamics of RO "on" mining projects, elucidating their profound impact on strategic decision-making.

Real Options "on" Mining Projects

Adelman and Watkins (1995) posit a unique perspective by characterizing proven reserves of ore as stockpiles, representing the culmination of investments in growth within mining economies. The inherent constraints and susceptibility to decay inherent in natural resources have spurred extensive research into the mineral economy. The diminishing production per unit of output leads to an increase in mining costs, a phenomenon grounded in economies of scale. This logic underscores the narrowing margin between gross output value and current outlay, reaching zero at the "economic limit" when production ceases.

Savolainen (2016) contributes a valuable insight, framing the early phases of a mining project, encompassing acquisition and exploration, as knowledge or investigation and development options. Sabour and Wood (2009) advocate for a model incorporating abandonment option costs as a function of open-pit size, as illustrated in Table 1 showcasing real options on mining projects. Zhang et al. (2015) highlight the importance of valuing projects early on, particularly when mine design is uncertain, thereby mitigating geotechnical uncertainty.

In the face of escalating uncertainty, Hasan et al. (2016) note a consensus among businesses in favor of employing dynamic and flexible methods such as Discounted Cash Flow (DCF) over clear, static approaches like Net Present Value (NPV) and Internal Rate of Return (IRR). The awareness of potential events casting shadows into the present emphasizes the necessity for future interest to equate to any retail price up to the present, a principle acknowledged by economists for long-standing durations.

Akbari et al. (2009) and Haque et al. (2016) exemplify the application of real options valuation in assessing the ultimate pit limit and utilizing RO in a hedging strategy for financing options in establishing a gold mine, respectively. Samis and Davis (2014) outline strategies aimed at establishing a high-level defense against fluctuating commodity prices. Whittle et al. (2007) contribute by applying a quantitative risk management method to enhance project values and fortify the robustness of mining projects, emphasizing the minimization of risk, optimization of variables, and the strategic disregard for future decisions. This comprehensive analysis underscores the multifaceted role of real options in shaping the trajectory of mining projects, aligning with the broader discourse on optimizing decision-making under uncertainty.

Table 1: Real Options" on" Mining Projects (Benndorf, Jorg et al., 2018)

R.O on Mining Investment	Class	Starts after	Ends through	Strategic Insights
Exploration (Study)	Call	Acquisition	Exploration	Commencement of geological studies and feasibility; critical for informed decision-making amid market volatility.
Development (Strategy)	Call	Exploration	Development	Transition from exploration to development; demands meticulous planning for potential infrastructure challenges and regulatory approvals.
Mining (Built)	Call	Development	Mining	Implementation of mining operations; necessitates a holistic approach addressing environmental impact and optimizing resource utilization.
Abandonment	Put	Acquisition	Abandonment	Decision point for project abandonment; demands rigorous economic viability assessment and strategic environmental rehabilitation planning.

Kim's (2010) proposal introduces a model for assessing the optimal control of projects through the utilization of Real Options (RO), emphasizing key factors such as ownership ratio, interaction impact, and expenses options. Notably, this strategy involves the application of RO on the framework without necessitating specific technical designs. This approach aligns with the dynamic Discounted Cash Flow (DCF) research conducted by Herbelot (1994) on coal-fired power plant projects, illustrating a parallel methodology focused on strategic decision-making and control optimization.

Real Options "in" Mining Projects at the Strategic Level

In the intricate realm of mining projects, the strategic application of Real Options (RO) plays a pivotal role in shaping production planning and design at a nuanced level. While attaining production planning and design may seem feasible if relative price variables followed a predictable pattern, the reality is marked by uncertainty. Linear programming (LP) procedures, mix-integer programming (MIP), and heuristics emerge as valuable tools to inject flexibility, manage uncertainty, and maximize value in engineering design, particularly at the initial project level within the mining sector (Bixby, 2012).

Delving into strategic mine design options, Newman et al. (2010) provide a comprehensive definition, characterizing 'mine design' as the identification of the mining system, encompassing geometric infrastructure arrangements, valuing production ability, and infrastructure capital, along with conducting comprehensive engineering design. Optimal production efficiency, mining techniques, and indicative cut-offs are integral components calculated in this process (Mayer and Kazakidis, 2007).

Armstrong et al. (2019) emphasize the significance of detailed investigations into the profitability of mineral deposits, intricately tied to the outcomes of exploration. Asad and Dimitrakopoulos (2012) advocate for a nuanced approach in selecting capacity, cautioning against sole reliance on reserves and expected product prices. Their study links decisions about capacity and stripping ratio to the target, highlighting the inherent interconnectedness. The concept of cut-off grade, defined as the standard grade of mineral deposits used for plant material feed, is explored by Sattarvand et al. (2015), emphasizing its critical role in the initial decision-making process, often framed as a challenge within the 'ultimate pit limit. While Thompson and Barr (2014) attempted to employ the RO methodology to assess cut-off grade under stochastic prices, the operational implementation struggled, evolving into an optimization problem later addressed by Mohammadi et al. (2017).

Variations in mine design and size can influence critical cost variables, such as road dimensions and the design or size of necessary equipment. The initial mine design can also encompass phased approaches based on diverse projects and geological considerations (Inthavongsa et al., 2016). Moving to mine planning options at the strategy level, Koushavand et al. (2014) highlight specific real options within the confines of a given mine design. Termed "planning" options, these strategies encompass the mine block extraction sequence, optimizing for maximum Net Present Value (NPV), managing exposure to production variation, addressing grade mixing concerns, and navigating pit slope restrictions. The intricacies of these planning options are visually presented in Figure 1, offering a comprehensive view of the strategic landscape within mining investments. This strategic depth in mine design and planning underscores the multifaceted role of real options in optimizing decision-making and value creation in the mining sector.

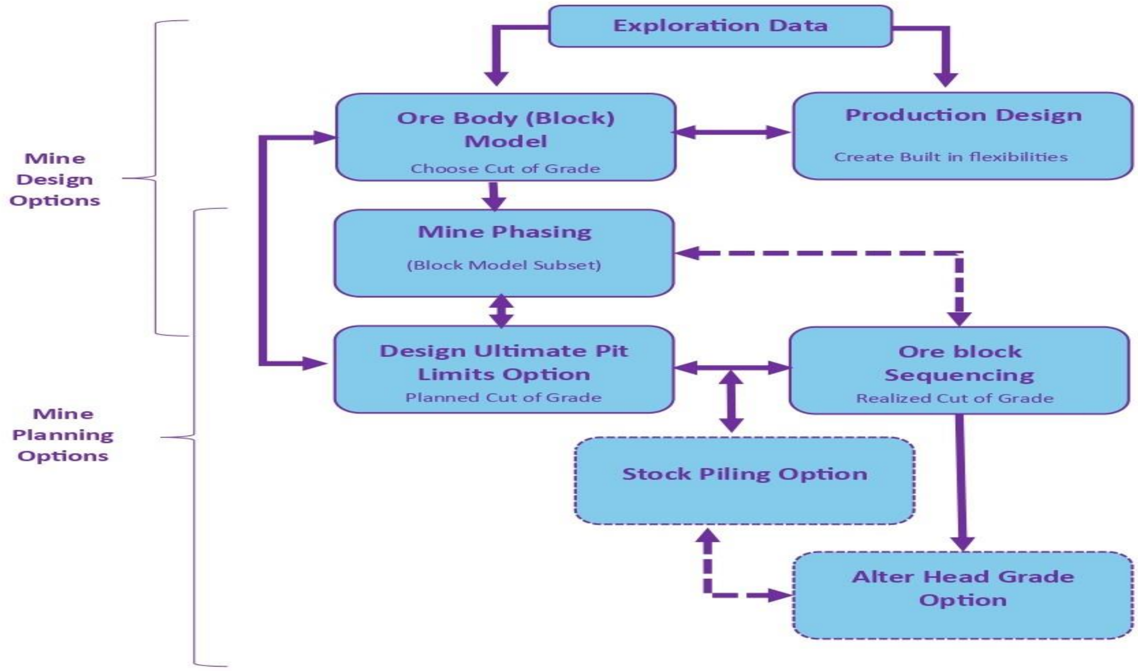


Figure 1: Design and Planning Options for Mine (after Savolainen, 2016b)

Strategic Expansion Option

As we delve into the strategic realm of mining projects, the consideration of expansion options becomes paramount after the initial production design ramp-up period. Sabour and Poulins (2010) underscore that substantial mining projects often evolve into multi-stage operations, extending their existence beyond the initially envisaged scope. These pivotal expansion options wield a substantial impact on the financial feasibility of the mining project. However, the decision to implement a mine expansion plan poses a challenge for decision-makers, demanding a nuanced assessment that factors in uncertainties and risks.

Building on this, Cortazar and Casassus (1998) offer insights gleaned from applying a real options methodology to evaluate a mining project. This approach not only increased the production rate but also brought about changes in the copper project's cost per unit, demonstrating the dynamic and transformative potential of strategic expansion options. In a contemporary context, Wu and Lin (2020) propose a strategic approach to address insufficient coal capacity production in China. Their recommendation involves temporarily withdrawing some coal capacity from the market, advocating against a uniform reduction in production rates across all coal mines. The study estimates the real options value of coal capacity, which surpasses the cost of a capacity exchange, highlighting the strategic and financial implications of expansion options in the coal mining sector.

Strategic Mine Closure Option

Moel and Tufano (2005) uncover that the decision to shut down a mine is intricately linked to company-specific management factors that extend beyond the conventional scope of the strict real options approach. Considerations such as the profitability of other mines in the company's portfolio and industry-wide factors are pivotal in this decision-making process. Amirshenava and Osanloo (2018) emphasize the adverse effects of mine closure and advocate for risk management strategies to mitigate these effects. The flexibility of temporary mine closure may be limited due to the intensity of mining capital, and methods have been developed to incorporate temporary closure and abandonment options in early mining assessments based on established models (Cortazar et al., 2008; Frimpong & Whiting, 1997; Slade, 2001).

Product Switch Options

Savolainen (2016b) brings forth a novel perspective on product switch options within the realm of mining investment. While limited references currently exist for their application, Savolainen suggests defining certain parameters as switch input options. The diversification of production, particularly in steel manufacturing, emerges as a potential avenue to generate significant value through product switch options. This approach serves as a strategic response to mitigate the impact of severe volatility in product prices and varying demand across different product ranges, showcasing the dynamic nature of decision-making within the mining sector.

Delay Mining Investment Option

Examining the strategic landscape of mining investments, the option to delay investment emerges as a significant real option. Rębiasz et al. (2019) delve into the intricacies of this option, framing it as a real option that allows a choice between investing now or waiting until the economy experiences growth—a decision influenced by the cost of capital promotion. Simultaneously, the hidden value of capital, represented as procurement esteem, is derived from the present value of net incomes. However, each year of delay results in the foregone revenues that could have been earned. This cost is proportionate to 1/T, with T representing the time for option expiration (Damodaran, 2015).

Staged Mining Investment Option

Ajak et al. (2019) shed light on the strategic advantages of staged mining investment options, providing management with the flexibility to adapt to market dynamics. These options empower projects to either extend operations if costs increase or cease when profitability becomes unsustainable. Notably, the allure of this option lies in the avoidance of resource expenditure on purchasing mining facilities and constructing processing plants, providing financial prudence. In summarizing the role of Real Options (RO) "in" mining projects, the operational versatility of initial-phase mining projects within the context of mine design and planning is evident. The flexibility required at the end of operations constrains decisions related to mine preparation and cut-off grades to the short term, as depicted in Table 2 illustrating the flexibility of real options "in" the mining project.

Feasibility improvements are effectively limited by the cumulative capabilities and alternative mine strategies developed for the remaining mineral deposit. The valuation of mine strategies and the provision of alternative techniques through the lens of real options is explored by Martinez & McKibben (2010), Stange & Cooper (2008), and Musingwini et al. (2007), underscoring the multifaceted role of real options in shaping strategic decisions within mining projects.

Table 2: Real Options" In" Mining Projects

R.O "In" Mining	Class	Opens after	Ends during	Strategic Insights
Delay investment	Flexibility	Development	Mining	Defer investment for better market conditions.
Stage investment	Built-in	Development	Mining	Optimize resource allocation through staged investment.
Pit design	Flexibility	Exploration	Abandonment	Optimize resource extraction with flexible pit design.
Block sequencing	Flexibility	Exploration	Abandonment	Determine optimal block sequencing for efficient mining.
Cut-off grade	Flexibility	Mining	Abandonment	Adjust cut-off grade based on market dynamics.
Stockpiling	Built-in	Mining	Abandonment	Strategically stockpile resources based on market demand.
Expand production	Built-in	Development	Mining	Flexibly expand production in response to increased demand.
Temporary closing	Flexibility	Mining	Abandonment	Temporarily close operations, adapting to market conditions.
Switch output	Built-in	Mining	-	Switch output based on changing market dynamics.

Flexibility and Uncertainty in Mining Investment

The mining industry, marked by its susceptibility to significant fluctuations in product prices, has become increasingly volatile, rendering mining operations less viable due to inadequate flexibility in responding to these changes (EY's Global Mining & Metals Center, 2015). The risk inherent in mining activities has made them less resilient in the face of uncertainty, impacting investor and purchaser confidence and challenging the economic feasibility in unpredictable circumstances.

In this dynamic environment, operational managers face immense pressure to adapt and enhance the focus of ongoing mining operations. The high uncertainty surrounding operating conditions and volatile product costs characterize mining ventures, emphasizing the critical role of flexibility in responding to changing circumstances (Groeneveld & Topal, 2011). Ajak et al. (2018) highlight flexibility as a central issue distinguishing mining operation, emphasizing the importance of operational flexibility in making decisions and delivering production targets with minimal losses during challenging periods.

The concept of flexibility, rooted in industrial practices, has been integral to the planning and design of mines. Singh & Skibniewski (1991) note the significance of flexibility as demand increases, new markets emerge, and unpredictability grows. The mining sector underwent substantial changes in the 21st century, marked by increased investment, the establishment of modern mines, and expanded production capacity (World Bank, 2018). Decision-makers acknowledge the uncertainty of the future, prompting discussions on adapting tasks to different conditions (Cardin et al., 2017).

Flexibility Options in Mining Systems

Flexibility stands out as a crucial component in the planning and design of mines, as noted by Kazakidis (2001). Mine schemes must exhibit ample flexibility to accommodate transitions in mining technology while achieving various project goals. Real options offer a valuable tool to assess flexibility in mining contexts, considering working and pricing risks and addressing instability and production delays related to ground-related issues (Chen et al., 2015; Vassilios N Kazakidis, 2001; Samis & Davis, 2014).

V. N. Kazakidis & Scoble (2003) emphasize that the effectiveness of production costs and schedules depends on the consideration of geological uncertainty and the expertise of the operating team. Decreasing the risk linked to expected production and cost schedules is a priority for mine planning teams, and more detailed information on parameters can enhance flexibility and mitigate risks. Real options serve as a means to test flexibility in the activities of mining systems, enabling the calculation of the likelihood of operational problems and their economic effects. The development of models that incorporate volatility due to different parameters enhances the optimization of mine plans. Table 3 illustrates comparative analysis of flexibility options in mining system.

Table 3: Comparative Analysis of Flexibility Options in Mining System

Flexibility Option	Key Considerations	Rating (1-5)	Notable Insights
Delayed Investment	Transitions in technology and project goals.	4	Defer investments for favorable market conditions.
Staged Investment	Manage working and pricing risks; address instability.	5	Optimize resource allocation through staged investment.
Flexible Pit Design	Consider geological uncertainty and team expertise.	4	Optimize resource extraction with a flexible pit design.
Block Sequencing	Mitigate risks linked to production and cost schedules.	4	Determine optimal block sequencing for efficient mining.
Adjustable Cut-off Grade	Evaluate economic effects of operational problems.	3	Adjust cut-off grade based on market dynamics.
Strategic Stockpiling	Calculate likelihood of production delays; economic impact.	5	Strategically stockpile resources based on market demand.
Expandable Production	Incorporate volatility due to different parameters.	5	Flexibly expand production in response to demand.
Temporary Closure	Enhance mine plans by incorporating parameter volatility.	3	Temporarily close operations, adapting to market conditions.
Output Switching		-	Switch output based on changing market dynamics.

(5): Exceptional - Highly effective in enhancing flexibility and mitigating risks.

(4): Strong - Significant positive impact on flexibility and risk management.

(3): Moderate - Adequate flexibility; improvements could be considered.

(2): Limited - Some flexibility, but potential improvements are necessary.

(1): Minimal - Ineffective in enhancing flexibility and managing risks

Uncertainty of Mining Projects

The extraordinary characteristics of every mining project lie in its high degree of uncertainty and the unpredictable shift in product costs, as highlighted by Groeneveld & Topal (2011). Heap hazards and uncertainties associated with distinct operations add further complexity, stemming from the industry itself, operating conditions, and geopolitical factors in the host country. The inherent uncertainty underscores the need for strategic approaches, such as real options, to navigate and optimize decision-making within mining projects. Distinguishing between market and mining project uncertainty provides a nuanced understanding, also known as external and internal uncertainty or exogenous and endogenous uncertainties within the mining projects (Figure 2). Industrial (endogenous) uncertainty possesses a key advantage—it tends to be less volatile and can be minimized through sufficient knowledge (Driouchi & Bennett, 2012).

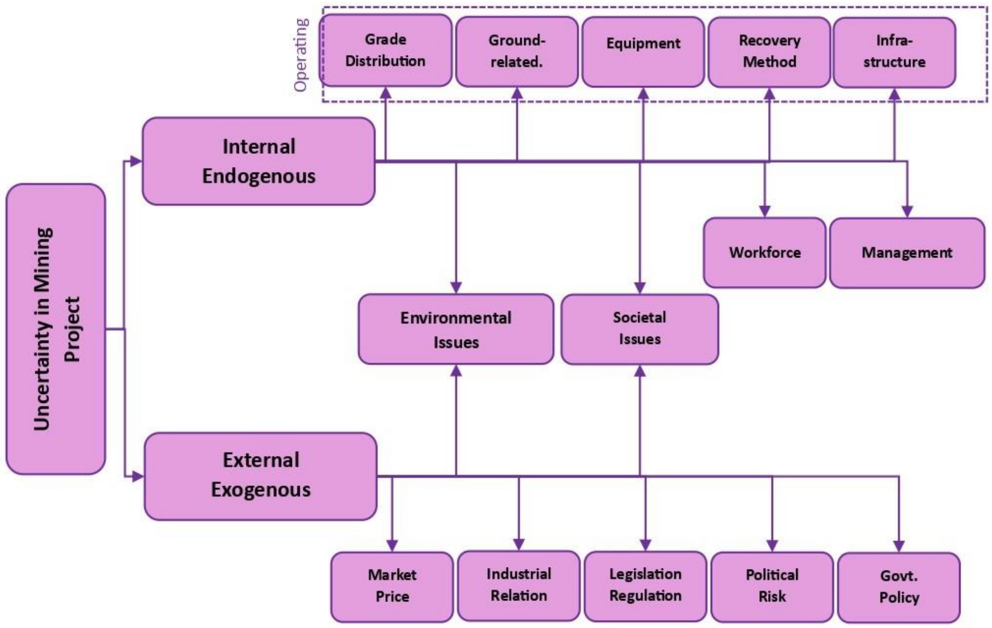


Figure 2: Uncertainty in Mining Projects (After V. N. Kazakidis & Scoble, 2003)

Conversely, exogenous (market) uncertainty is characterized by unpredictable volatility, and future principles cannot be determined until they unfold. This distinction highlights the dynamic interplay between factors within the industry itself, shaped by operational conditions and knowledge, and external market forces subject to unpredictable fluctuations. Navigating these dual uncertainties calls for strategic approaches that can adapt to the inherent complexities of both endogenous and exogenous factors in mining projects.

Guj & Garzon (2007) delve into the pivotal role of stochastic external market volatility in the context of mining projects. Future metal prices available on the market serve as equivalents of certainty in the project assessment process. However, the maturity of these prices depends on the commodity, typically spanning two to five years. Savolainen (2016a) addresses price uncertainty by modeling expected standards using stochastic differential equations, with the Brownian Geometric Movement (GBM) being a commonly applied SDE exhibiting distributed returns over time. Another category of SDEs is the mean-reversion equations, operating on the assumption that prices will revert to the long-term average cost of production (Botin et al., 2013).

Ore body uncertainty presents an additional significant challenge in mine planning, distinct from stochastic price uncertainty and other economic variables. Unlike price uncertainty, waiting does not resolve ore body uncertainty; it diminishes only through exploration and development strategies before mining (Jorg Benndorf & Dimitrakopoulos, 2018; Meagher et al., 2009). Ensuring successful mining activities necessitates achieving production objectives in terms of ore quantity and quality, considering in situ variabilities of grades. Uncertainty regarding the spatial distribution of ore and quality parameters results in variations in production aims and overall financial shortfalls (J. Benndorf & Dimitrakopoulos, 2013). Osterholt & Dimitrakopoulos (2018) developed a multi-point strategy to capture uncertainty in iron ore mining. Uncertainty profoundly influences mining processes, with product prices and geology recognized as the most critical risk factors. Acknowledging these uncertainties at an early stage is vital for project progress, enabling a more realistic strategy through annual re-evaluations. F. Del Castillo & Dimitrakopoulos (2014) present a real-life assessment evaluating the effects of uncertainty on the life of a pit mining operation and the resulting alterations in the final pit limit.

Real Options Srategical Tools for Valuation Mining Project Planning

Ajak et al. (2019) emphasizes the qualitative and analytical nature of the real options approach. Consequently, the selection of real options analytical strategies involves not only a quantitative perspective but also a qualitative understanding of the real options to classify options. Various methods for valuing real options in projects vary based on the project's nature and the surrounding circumstances (Atari et al., 2019; Lambrecht, 2017).

In this study, we delve into the most critical strategic tools for real options:

Black and Scholes Model

Originally proposed by Black & Scholes (1973), the Black and Scholes model was developed to evaluate options for trading assets, particularly stocks and bonds. While well-suited for analytical solutions of European options, the model faces limitations in estimating real projects with multiple uncertainties, especially those involving a compound American real option. The strength of the Black and Scholes model lies in its sensitivity to measure many option prices over a short period. However, when dealing with an American-style exercise, the model may not accurately analyze the option's price at maturity (Le Bellac & Viricel, 2017).

The Black and Scholes equation is shown in Eq. (1).

$$f = S_N(p_1) + N(p_2)Qe^{2-rt} \tag{1}$$

Both p_1 and p_2 are determined in Eqs. (2) and (3).

$$p_1 = \frac{\ln\frac{S}{Q} + \left(r + \frac{S^2}{2}\right)t}{\sqrt[\sigma]{t}} \tag{2}$$

$$p_2 = p_1 - \sqrt[\sigma]{t} \tag{3}$$

Where ;

f = price of the call option

S= stock price

t = Time until option maturity

Q= Option striking price

r=risk free interest rate

N = Cumulative standard of normal distribution

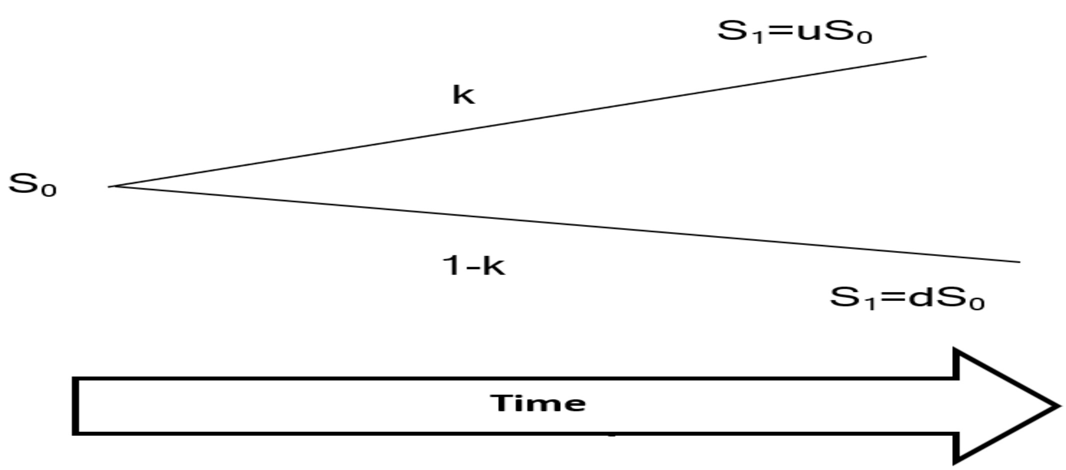
e =constant which is ~ 2.71828

σ = price volatility.

As demonstrated by Eqs (2) and (3), the model is divided into two distinct parts. The first part, $S_N(p_1)$, increases the risky asset price by adjusting the call price associated with the underlying price variability. The second part, $N(p_2)Qe^{2-rt}$, represents the present value (PV) of paying the exercise price at maturity and is applicable to European options only, available on the expiry day (Han et al., 2018).

Option Pricing Trees (Binomial Model)

As described by Gottesman (2016), the option price tree, also known as a lattice, is frequently based on the binomial price model introduced by Cox et al. (1979) and serves as a widely employed method for option evaluation. Unlike relying on a probability density function (PDG) or volatility estimate, this model focuses on likelihood distributions toward certain state variables. The fundamental concept of the binomial tree model involves considering just two potential asset value states—either an increase or a decrease. The core idea of a binomial tree model is outlined as follows:



Value of the asset in t_1

$$S_0 = \frac{[k.uS_0 + (1-k).dS_0}{(1+r)^t} \tag{4}$$

Where ;

S_0 = stock price value

k = path probability

u = factor for path "up" by which the price falls.

d = factor for path "down" by which the price falls.

Real Options Strategical Tools for Valuation Mining Project Planning

Ajak et al. (2019) emphasized that the real options approach is qualitative and analytical, with the strategy selection relying not only on a quantitative perspective but also on the qualitative system that classifies real options. Various methods for real options to valuation projects differ based on the project's nature and surrounding circumstances (Atari et al., 2019; Lambrecht, 2017).

Black and Scholes Model

Introduced by Black & Scholes (1973), this model was designed to evaluate options for trade assets, particularly stocks and bonds. While the Black and Scholes model is effective for analytical solutions of European options, its main strength lies in measuring numerous options prices over a short period. However, it falls short in accurately analyzing the price of options with American-style exercise at maturity (Le Bellac & Viricel, 2017).

Option Pricing Trees (Binomial Model)

Dimitrakopoulos & AbdelSabour (2007) highlighted the binomial model's accuracy in pricing American options as a significant advantage over the Black-Scholes model. However, its drawbacks include a slow rate and complexity with many nodes, making it challenging to perform and impractical in certain situations. This model has been applied in mining investment valuation in various studies (Ajak & Topal, 2015; Ardian & Kumral, 2020; Dehghani et al., 2014).

Monte-Carlo-Simulation

The Monte-Carlo-Simulation computes multiple asset price paths using a stochastic price process, providing a flexible means to adapt to specific application requirements. However, it requires a substantial amount of computational time and struggles with situations involving early exercise opportunities (Barbu & Zhu, 2020). This simulation has found application in tunneling planning, open-pit short-term planning, and various aspects of mining projects (Vargas et al., 2014, 2015; Upadhyay & Askari, 2018).

Least Squares Monte-Carlo-Simulation (LSM)

Established by Longstaff & Schwartz (2001), LSM is effective for evaluating American call options in multidimensional difficulties. It aims to estimate American options' value with low computational effort while providing high-quality performance. LSM has been applied in mining projects for modeling multi-metal mines (Abdel Sabour & Poulin, 2006; Lemelin et al., 2006; S. A. Sabour & Poulins, 2010).

Mixed Integer Linear Programming (MILP)

MILP has been used to optimize long and short-term open-pit scheduling by incorporating geological uncertainty into mine planning. It can address various mining constraints and has shown to generate higher net present value (NPV) in open-pit production scheduling plans (Moreno et al., 2017; Eivazy & Askari-Nasab, 2012; Samavati et al., 2018; Ramazan & Dimitrakopoulos, 2013; Y. Li et al., 2018; Khan & Asad, 2020; Chatterjee & Dimitrakopoulos, 2020).

Geometric Brownian Motion (GBM)

GBM, a model describing the movement of time sequence variables and asset prices, has been applied to treat uncertainty in metal prices and operating costs in mining projects (Gligoric et al., 2020; Ramos et al., 2019; Savolainen et al., 2017).

Decision Making with Dynamic Programming

Dynamic programming (DP) has been widely used in mining projects to make optimal decisions considering geological and commodity price uncertainty (Rimélé et al., 2020; M. F. Del Castillo

& Dimitrakopoulos, 2019; Biswas et al., 2020; Inthavongsa et al., 2016). DP transforms complex decision-making problems into interconnected subproblems, allowing efficient optimization in the face of uncertainties.

2.0 CONCLUSION AND RECOMMENDATIONS

This paper has provided a comprehensive review and discussion on the strategic application of real options for optimizing mining project planning under uncertainty. The exploration of real options strategies, such as project delay, reduction, or abandonment, has revealed their potential to transform economic and geological uncertainties into strategic opportunities through the utilization of specific tools. The study has emphasized that real options play a crucial role in the evaluation and optimization of mining project planning.

One key insight from the reviewed literature is the recognition that the value enhancement brought about by real options is not merely a matter of proving their impact on project value. Rather, the focus lies in the strategic and operational adaptation of these options, particularly within the dynamic and uncertain context of mining investments, where projects continuously confront an uncertain future.

Based on the insights gleaned from the literature, it is evident that simulation and dynamic programming emerge as preferred strategical tools for the valuation and optimization of mining project planning. Simulation offers flexibility and adaptability to specific application requirements, making it a versatile choice in situations where typical financial option properties may not fully comply. On the other hand, dynamic programming, with its ability to handle complex decision-making problems efficiently, proves to be a robust approach for overcoming geological and commodity price uncertainties.

While the literature provides valuable insights into the strategic application of real options and associated tools, there are opportunities for further exploration and enhancement in this domain. Future research could delve into refining simulation models to address early exercise opportunities and computational time challenges, making them even more applicable to mining projects. Additionally, advancements in dynamic programming methodologies tailored to the unique challenges of mining, such as the integration of evolving geological uncertainties, could further contribute to the strategic optimization of mining project planning.

In conclusion, this paper underscores the importance of embracing real options strategically in the mining industry to navigate uncertainties effectively. The adoption of simulation and dynamic programming as preferred tools offers a promising avenue for enhancing the valuation and optimization of mining project planning. Future endeavors in this field can build upon these foundations to develop more robust and tailored approaches that align with the dynamic nature of mining investments.

In conclusion, this paper contributes significantly to theory, practice, and policy in the field of mining project planning. The exploration of real options strategies and associated tools offers practical guidance for industry practitioners, helping them navigate uncertainties effectively and optimize decision-making processes. From a theoretical standpoint, our study advances understanding by emphasizing the applicability and effectiveness of real options theory in mining investments. Additionally, our findings highlight the importance of regulatory frameworks that support the strategic integration of real options in mining project planning, underscoring the role of policymakers in fostering industry resilience. Overall, our study provides a comprehensive framework for enhancing project valuation and optimization, ultimately contributing to the sustainability and competitiveness of the mining sector.

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