A SYSTEM DYNAMICS DECISION MODEL FOR MINING INVESTMENTS

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ABSTRACT

A SYSTEM DYNAMICS DECISION MODEL FOR MINING INVESTMENTS

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Emerging markets represent a dynamic and rapidly evolving segment of the global economy, distinguished by significant growth potential and increased investment opportunities. These markets are undergoing substantial economic transformations, including industrialization, urbanization, and advancements in infrastructure. This thesis study aims to develop a mining investment decision model that considers the principal drivers and challenges associated, especially with emerging markets, such as political instability, regulatory environments, and market volatility, particularly concerning mining investment decisions, through system dynamics.

The study uses system dynamics modeling with stock-and-flow diagrams to reveal the nonlinear relationships that influence the interplay between investment decision-making and emerging markets. The simulation model incorporates data from literature, official reports, and expert opinions to develop dependencies between positively and negatively correlated factors and their impact on investment decisions. The study's main objective is to identify key leverage points within the decision system by examining endogenous and exogenous parameters, thereby offering valuable insights for investment decision-making in the mining industry within emerging markets.

The model utilizes five key submodules: Valuation, production, growth strategy, demand, and finance. Through a structured methodology involving system decomposition, case studies, and sensitivity analyses, the model is calibrated to simulate a hypothetical copper mine investment, estimating an enterprise value of 78.9 million USD and a target growth rate of 11.2%. Results highlight the significant influence of operating costs, capital management policies, and market conditions on free cash flow and mineral reserves. Ultimately, this model offers mining investors a comprehensive tool to identify optimal investment strategies across various development stages and mineral types.

Keywords: Dynamic Complexity, Mining Investment Decision Making, System Dynamics, Project Evaluation, Emerging Markets

ÖZ

MADENCİLİK YATIRIMLARINA YÖNELİK BİR SİSTEM DİNAMİĞİ KARAR MODELİ

Gökçe, Berk
Yüksek Lisans, Maden Mühendisliği
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Gelişen pazarlar, küresel ekonominin dinamik ve hızla değişen bir segmentini temsil etmekte olup, önemli büyüme potansiyeli ve artan yatırım fırsatları ile karakterize edilmektedir. Bu pazarlar, sanayileşme, kentleşme ve altyapı iyileştirmeleri gibi önemli ekonomik dönüşümlerden geçmektedir. Bu çalışma, siyasi istikrarsızlık, piyasa oynaklığı ve düzenleyici çevreler gibi bilhassa gelişen pazarlarla ilişkili temel etmen ve zorlukları dikkate alarak maden yatırım için karar destek mekanizması oluşturacak bir sistem dinamiği modeli geliştirmeyi amaçlamaktadır.

Çalışma, yatırım karar verme süreci ve gelişen pazarlar arasındaki etkileşimde rol oynayan doğrusal olmayan ilişkileri açıklayabilmek için stok-akış diyagramlarını içeren sistem dinamiği modellemesi kullanacaktır. Geliştirilecek simülasyon modeli, pozitif ve negatif ilişkili faktörler arasındaki bağımlılıkları ve bunların yatırım kararları üzerindeki etkilerini incelemek için literatürden, resmi raporlardan ve uzman görüşlerinden elde edilecek verileri değerlendirecektir. Çalışmanın ana amacı, karar sistemi içindeki ana etki noktalara ait değer değişimlerini, harici ve dahili sistem parametrelerini inceleyerek belirleyebilmek ve böylece gelişen pazarlardaki madencilik sektörü yatırım kararlarına yönelik değerli içgörüler sunabilmektir.

Model, değerleme, üretim, büyüme stratejisi, talep ve finansman olmak üzere beş ana modülü içermektedir. Sistem ayrıştırması, vaka çalışmaları ve duyarlılık analizlerini içeren yapılandırılmış bir yöntemle model, hipotetik bir bakır madeni yatırımını simüle edecek şekilde kalibre edilmiştir ve 78,9 milyon ABD doları işletme değeri ile %11,2 hedef büyüme oranı tahmin etmektedir. Sonuçlar, işletme maliyetleri, sermaye yönetimi politikaları ve piyasa koşullarının serbest nakit akışı ve mineral rezervleri üzerindeki önemli etkisini vurgulamaktadır. Nihayetinde, bu model, madencilik yatırımcılarına çeşitli gelişim aşamaları ve mineral türleri arasında optimal yatırım stratejilerini belirleme konusunda kapsamlı bir araç sunmaktadır.

Anahtar Kelimeler: Dinamik Karmaşıklık, Maden Yatırımlarında Karar Verme, Sistem Dinamikleri, Proje Değerleme, Gelişen Pazarlar

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CHAPTER 1

INTRODUCTION

1.1 Background

The term emerging market was first called in the early 80s by the World Bank to encourage reluctant investors to join an equity fund focused on investing in emerging countries. Emerging markets are defined as nations undergoing significant economic expansion and exhibiting certain attributes of a developed economy, although they do not yet fully meet all the criteria associated with developed markets. They currently serve as the largest global producer of crucial raw materials, and various global companies such as Vale, Tata Steel, and Zijin Mining are operating actively. Several factors have motivated mining companies to be available in emerging markets in the last decades. Some of them can be listed as follows: (i) market liberalization and the privatization of state-owned enterprises, (ii) preferential access to substantial and underutilized local resources, (iii) the pursuit of geographic and commodity diversification, and (iv) strategic expansion aimed at securing raw material supplies for metallurgical operations.

The positioning in emerging markets is not always straightforward because the market conditions are unstable, which is crucial for the mining sector because of the following reasons: i) the capital-intensive nature of mining necessitates substantial initial investment; (ii) the pricing of mineral products is governed by global market conditions; and (iii) mining operations exhibit substantial socio-economic and environmental interactions with local and regional authorities and communities. In an emerging market, critical problems are related to financial risk and several versions of resource nationalism. Emerging markets generally have higher country risk premiums and lack financial stability. Behind these factors, these countries lack a robustly supportive regulatory environment. One of the additional challenges for emerging markets is the insufficiency of a solid domestic base of skills and knowledge. Company management generally lacks international experience and business practices outside the emerging markets.

Therefore, investment decision processes, especially for new projects in emerging markets, are exposed to challenges mainly related to financial, institutional, political, or other domestic considerations. As mentioned earlier, mining projects are also expected to experience many problems and decision parameters that differ from those of other sectors. Increasing mining projects in emerging countries will provide significant benefits to the related countries by recovering undeveloped resources and contributing to gross national products with an advance in commodity diversity; however, the inherent and induced uncertainties of investing in an emerging country should be regarded in the decision-making stages of mining investments.

In this sense, the present study aims to develop a system dynamics model for facilitating the decision-making processes for mining investments, especially in emerging markets under uncertainty. The model structure can also be adapted to investment decisions in developed and frontier countries. The developed model is also implemented for a case study project covering the dominant conditions of an emerging market.

1.2 Problem Statement

Investment decision refers to the strategic choices regarding the allocation of a firm's resources to maximize returns for investors. This condition involves making long-term financial decisions across various markets and conditions. The markets are categorized into three groups according to the Morgan Stanley Capital International Market Classification Framework, as illustrated in Figure 1.1.

Criteria	Frontier	Emerging	Developed
A Economic Development			
A.1 Sustainability of economic development	No requirement	No requirement	Country GNI per capita 25% above the World Bank high income threshold* for 3 consecutive years
B Size and Liquidity Requirements			
B.1 Number of companies meeting the following Standard Index criteria	2	3	5
Company size (full market cap)**	USD 1,033 mm	USD 2,066 mm	USD 4,133 mm
Security size (float market cap)**	USD 73 mm	USD 1,033 mm	USD 2,066 mm
Security liquidity	2.5% ATVR	15% ATVR	20% ATVR
C Market Accessibility Criteria			
C.1 Openness to foreign ownership	At least some	Significant	Very high
C.2 Ease of capital inflows / outflows	At least partial	Significant	Very high
C.3 Efficiency of operational framework	Modest	Good and tested	Very high
C.4 Availability of investment instruments	High	High	Unrestricted
C.5 Stability of the institutional framework	Modest	Modest	Very high

* High income threshold: 2021 GNI per capita of USD 13,205 (World Bank, Atlas method)
** Minimum in use for the May 2023 Index Review, updated on a quarterly basis

Figure 1-1. Morgan Stanley Capital International Market Classification Framework

As previously noted, emerging markets are economies showing significant economic growth and possessing some, though not all, traits of developed economies. These markets represent countries in transition from frontier to developed status. The common features of emerging markets include market volatility, growth and investment potential, high economic growth rates, and political and financial instability. Risks associated with international investing can generally be classified as financial, economic, or political. Financial risks often involve capital-related issues, such as loan defaults or difficulties in repatriating profits. Economic risks may encompass fluctuations in a country's economy, such as inflation rates, current account balances, and restrictive regulations. Political risks may include government instability, expropriation, bureaucratic inefficiency, corruption, and conflict (Harrington et al., 2021). Those risks are listed on MSCI (Morgan Stanley Capital International) Emerging Market studies as the value, size, momentum, quality, yield, and volatility.

The mining sector is capital-intensive, so a large amount of capital upfront is required for investment. Deciding which projects are most suitable for investing and checking the decision based on subjective reasoning is vital for achieving higher NPV under uncertain conditions and minimizing project risks. In this regard, the investment decisions for mining companies in an emerging market include various combinations of subjective and objective estimation and judgments of decision makers. Therefore, investment decision processes in emerging markets must be performed carefully by including several uncertain factors with their complex and nonlinear interactions to ensure proper investment sustainability. Otherwise, investments, especially in mining, that cover many unique risk factors may cause drastic and unforeseen drops in companies' financial stability if all the related technical and nontechnical factors are not evaluated jointly and extensively. In this sense, implementing a system dynamic model for investment decision-making problems can potentially improve the decision-making process because it can represent dynamic interactions in a complex system.

1.3 Objectives and Scopes of the Study

The main objective of this study is to develop an investment decision model using the system dynamics method for mining investments, especially in emerging markets, where uncertainty factors are mainly related to political, social, financial, and environmental aspects. Sub-objectives of this research study are as follows:

i) Identifying mining investment characteristics in emerging markets,

ii) Developing a system dynamic model to understand interactions among decision and market conditions,

iii) Generating a dataset reflecting the nature of an emerging country,

iv) Executing the investment decision model in a System Dynamics (SD) environment and

v) Analyzing the effects of the investment decision criteria on the success of the investment.

1.4 Research Methodology

This thesis study utilizes system dynamics modeling to examine the stages of investment decision-making within the mining industry in emerging markets. The research methodology applied in this study is depicted in Figure 1.2.

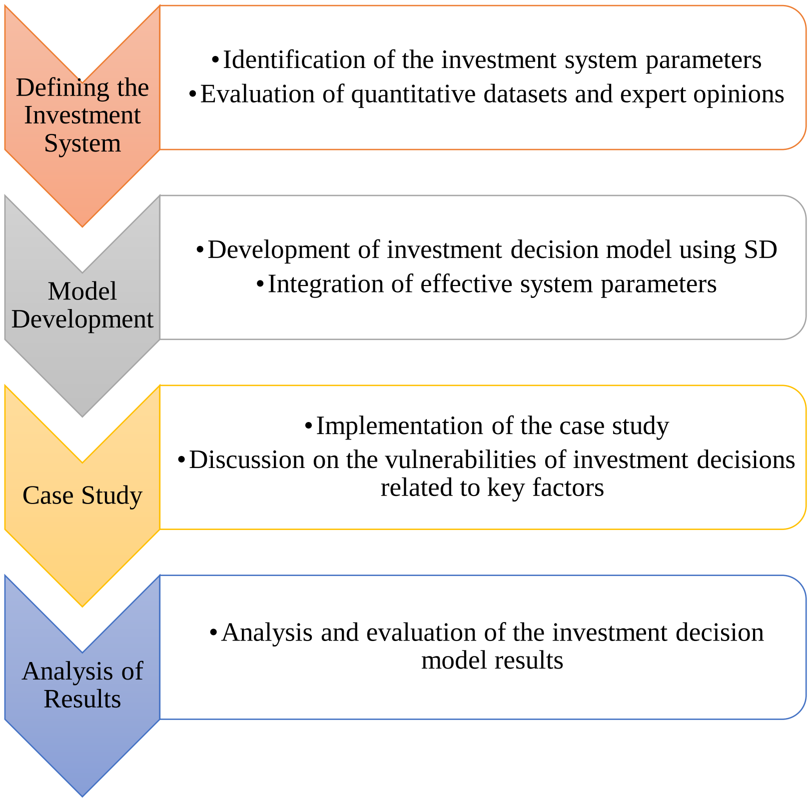

Figure 1-2: Research Methodology of the Thesis Study

The main research methodology steps are given as follows:

i. Identifying the investment structure, functional dependencies, and boundaries by decomposing the system into its components depends on evaluating subjective and objective data.

ii. Development of investment decision model in system dynamics (SD) environment by introducing the system configuration, decision model boundaries, and dependencies.

iii. Implementation of a case study and evaluation of the introduced parameters with monitoring and reporting system output.

iv. Output and sensitivity analysis of the system for different investment decision scenarios with varying parameters.

1.5 Significance and Expected Contributions of This Thesis

Although various studies have been performed on investment decision-making, the system dynamic modeling of mining investments in emerging markets has not been studied. Moreover, the literature on implementing investment decision-making processes in mining is highly limited. In this sense, the current study intends to develop a system dynamic investment decision model to facilitate investment decision processes for mining companies, especially in emerging markets.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section begins by defining terms associated with investment valuation, including its classification, working principles, and methods, thereby providing a comprehensive foundation on the subject. Additionally, it examines the valuation of mineral properties in accordance with international valuation codes and standards, as well as the factors influencing investment decision-making within the mineral industry. Lastly, concepts of system dynamics are extensively discussed.

2.2 Investment Valuation Approaches

Valuation is the process of determining the total economic value of a company, project, investment, or asset. A business value assessment requires evaluating all related key and triggering aspects. The valuation process can be performed for varying reasons, primarily to determine the sales value of a project for buying or selling a business, asset value, tax reporting, strategic planning, and forecast of the future financial performance of a project or asset.

Valuation of assets or projects needs estimation of periodic cash flows. The organizing principles of future cash flow, depending on the organizational structure, can be explained by various principles jointly as follows (Mercer and Harms, 2021):

- Principle of Expectations: Value is based on expected future cash flow and deals with uncertainty. Any valuation is a projection of the expected future performance of businesses; therefore, unrealistic expectations decrease the confidence level of the investment.

- Principle of Growth: The current value of an asset is influenced by expectations of future growth. Change and growth are fundamental aspects of economies and businesses, establishing a fundamental connection between growth and value over time.
- Principle of Risk and Reward: The relationship between risk and reward impacts value. It means that while the risk increases, the reward also increases up to investors' risk appetite.
- Present Value Principle: The value of a business is determined by the present value of anticipated future cash flows, discounted to today’s value at a rate that reflects the associated risks. This principle encompasses four investment aspects: cash flow characteristics, duration, risk attributes, and anticipated value growth.
- Principle of Alternative Investments: Businesses and business investments are valued for reasonable alternatives and competing investments. Companies have several types of buyers, such as financial, strategic, and synergistic buyers, so buyers' investment decisions are based on the highest income with less risk for their investment.
- Principle of Rationality: The markets are rational and consistent in this principle. So, the valuation of any asset should be rational, consistent, and reasonable to dispel doubt on the critical investment decision-making process.

Managing cash flow using these principles and assessing a business's success or failure probability should be conducted systematically by capturing value and generating investment opportunities. In this context, precise investment valuation is crucial, serving as the primary comprehensive and long-term criterion for investment decision-making (Brealey et al., 2011; Koller et al., 2010). There are three standard valuation approaches for an accurate investment valuation: cost, income, and market. The following subsections will focus on the details of these approaches.

2.2.1 Cost Approach

According to the International Valuation Standards (2022), the cost approach determines a business's value based on the principle that a buyer will not pay more for an asset than the cost of acquiring an asset of equal utility from scratch, whether through purchase or construction unless there are significant factors such as time, inconvenience, or risk involved. This approach estimates value by calculating the asset's current replacement or reproduction cost and subtracting deductions for physical deterioration and other forms of obsolescence.

The cost approach is applicable under the following conditions: i) when the asset can be replicated with the same utility and without significant restrictions or premium for immediate use, ii) when income or market approaches are not feasible, and the asset is not directly income-generating, or iii) when the value is based on replacement cost. The three main methods used in the cost approach are replacement cost, reproduction cost, and the summation method.

The replacement cost method involves determining the price to replace an asset with a similar utility in current market conditions. The critical steps in this method are i) calculating the costs of creating or obtaining an equivalent asset, ii) assessing depreciation due to physical, functional, and external obsolescence, and iii) subtracting total depreciation from the total costs to establish the asset's value.

The reproduction cost method is the second cost approach, which refers to the cost of an asset being replicated instead of an asset being valued. The critical steps in the reproduction cost method are i) calculating all the costs of creating a replica of the valued asset, ii) determining the depreciation of the valued asset relevant to physical, functional, and external obsolescence, iii) deducting total deprecation from the total costs to determine the value of the subject asset.

The summation method, also known as the underlying asset method, values an asset based on the value of its components and is used for investment companies or other asset types. Steps include i) valuing each component using appropriate valuation methods and ii) aggregating the values of these components to find the total value of the subject asset.

2.2.2 Market Approach

The market approach values a business by comparing it to identical or similar assets for which price information is available. This approach is appropriate under the following conditions: i) when the subject asset has been recently sold in a relevant transaction, ii) when the asset or similar assets are actively traded publicly, and/or iii) when there are frequent and recent transactions involving similar assets.

The comparable transactions method, also known as the guideline transactions method, is a market approach technique that derives value based on transactions involving similar assets. Key steps include i) identifying units of comparison used in the market, ii) locating relevant comparable transactions and calculating key valuation metrics, iii) conducting a comparative analysis of qualitative and quantitative similarities and differences, iv) adjusting valuation metrics for differences between the subject and comparable assets, v) applying these adjusted metrics to the subject asset, and vi) reconciling value indications if multiple metrics are used.

The comparable transaction method can use a variety of units of comparison, which form the basis of the comparison. For instance, price per square meter, rent per square meter, and capitalization rates can be utilized to value a real property.

2.2.3 Income Approach

The income approach values a business by converting expected future cash flows into a single present value. This approach determines an asset's value based on the income, cash flow, or cost savings it is expected to generate. It is particularly suitable under the following conditions: i) when the asset’s income-generating ability is a critical factor for its value from an investor’s perspective, and/or ii) when there are limited or no relevant market comparables for the asset but reasonable projections of future income are available. The income approach assumes that investors expect a return on their investment, incorporating perceived environmental risks.

The income approach commonly uses the discounted cash flow (DCF) method. It calculates the present value of an asset by discounting its projected future cash flows. Key steps in the DCF method include i) selecting the most appropriate type of cash flow based on the asset's characteristics, ii) determining the explicit forecast period for cash flows, iii) preparing a cash flow forecast for that period, iv) deciding whether a terminal value is necessary at the end of the forecast period and determining its value if applicable, v) selecting an appropriate discount rate, and vi) applying this discount rate to the projected future cash flows to derive the asset's present value.

A crucial aspect of the DCF method is choosing the type of cash flow. Valuers must select the appropriate cash flow type considering factors such as i) whether it pertains to the entire asset or partial interest, ii) whether it is pre-tax or post-tax, iii) whether it is nominal or real, iv) the currency used, and v) the specific cash flow elements included in the forecast. At this point, relying on the discussion in Section 2.2, Section 2.3 will address the valuation of mineral properties.

2.3 Valuation of Mineral Properties according to International Valuation Codes

This chapter discusses the valuation of mineral properties using available information from experts and exploration, pre-development, development, and production stages. This chapter is structured into two parts. The first part provides an overview of the standard development stages of mining projects and prevalent mineral classification criteria. The second part explores the valuation frameworks and standards utilized in the mining industry, tailored to various project stages.

2.3.1 The Mineral Development Stages

The mining industry primarily focuses on exploring, discovering, and extracting non-renewable raw materials that have economic value and are pivotal globally.

Additionally, subsequent objectives encompass processing these raw materials to produce marketable products such as copper blister, gold doré, and metallurgical coal. Here, the mining project lifecycle can be handled in four main parts: i) exploration works and discovery of the commodity, ii) development, iii) mining production, processing, and metallurgy (if any), and iv) reclamation and rehabilitation.

The decision to commence the production of a commodity necessitates a careful evaluation of financial trade-offs to compensate for capital expenditures, which are particularly significant during the exploration and development phases. Therefore, it is crucial to carefully determine the financial value of mineral properties and the approach and methods to be employed during the exploration or development stages.

Clear definitions of mineral resources and reserves should be established before initiating the valuation process. Technical information on mineral resources and the reserves of the related commodities serve as the most crucial data for mineral property investors. The mineral resource refers to a concentration or occurrence of solid material of economic interest within the Earth's crust, characterized by its form, grade, quality, and quantity such that there are reasonable prospects for its eventual economic extraction. The location, quantity, grade or quality, continuity, and other geological attributes of a mineral resource are determined through specific geological evidence and knowledge, including sampling.

Conversely, a mineral reserve represents the economically mineable portion of a measured and/or indicated mineral resource. It accounts for diluting materials and potential losses that may occur during mining or extraction and is defined based on studies conducted at a pre-feasibility or feasibility level, including the application of modifying factors as outlined by CIM Definition Standards. Figure 2.1 illustrates the relationships between exploration results, mineral resources, and ore reserves.

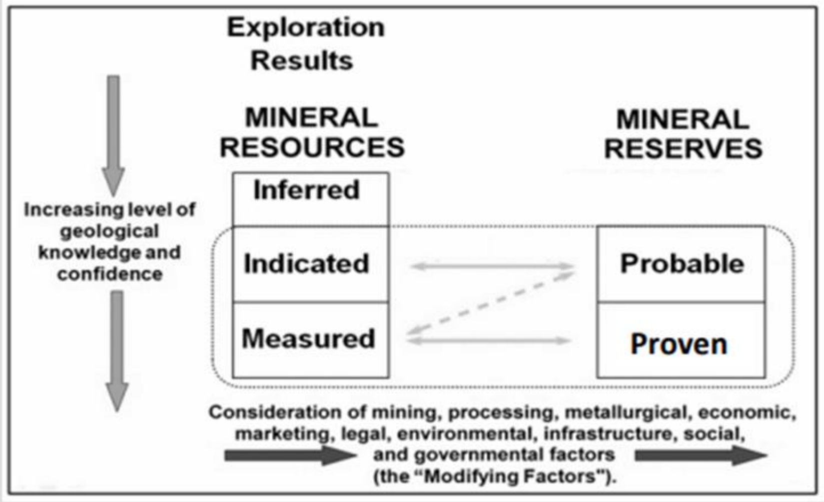

Figure 2-1: General Relationship between Exploration Results, Mineral Resources, and Ore Reserves (JORC Code, 2012)

According to the CIMVAL Code (2019), mineral properties are classified into four groups: i) exploration properties, ii) mineral resource properties, iii) development properties, and iv) production properties. These categories do not have distinct boundaries and evolve over time. A detailed discussion of the categories of mineral properties is given below.

An exploration property is a mineral property that does not have mineral reserves or resources and for which economic viability has not been established. A mineral property encompasses any rights, titles, or interests related to the exploration, development, extraction, or processing of minerals on or beneath the surface, including all fixed plant, equipment, and infrastructure used for these activities. It can include real property, unpatented mining claims, prospecting and exploration permits and licenses, development permits and licenses, mining licenses and leases, leasehold patents, crown grants, licenses of occupation, patented mining claims, and royalty interests.

A development property is defined as a mineral property with established mineral reserves and/or resources where economic viability has been confirmed through a feasibility or pre-feasibility study. It encompasses properties with positive feasibility or pre-feasibility studies that have not yet been exposed to production. Conversely, a production property is an operational mine that may or may not include a processing plant that has been fully commissioned and actively producing.

As previously indicated, Figure 2.1 illustrates the relationship between mineral resources and reserves, emphasizing that the accuracy of ore reserve estimates is directly linked to enhanced geological knowledge and confidence. This relationship also applies to project value, with the connection between certainty and project value shown in Figure 2.2. The figure highlights a need for increasingly confident information on mineral properties throughout the mining project stages, from discovery to project commissioning. The following subsections will discuss the valuation frameworks for mineral properties in detail.

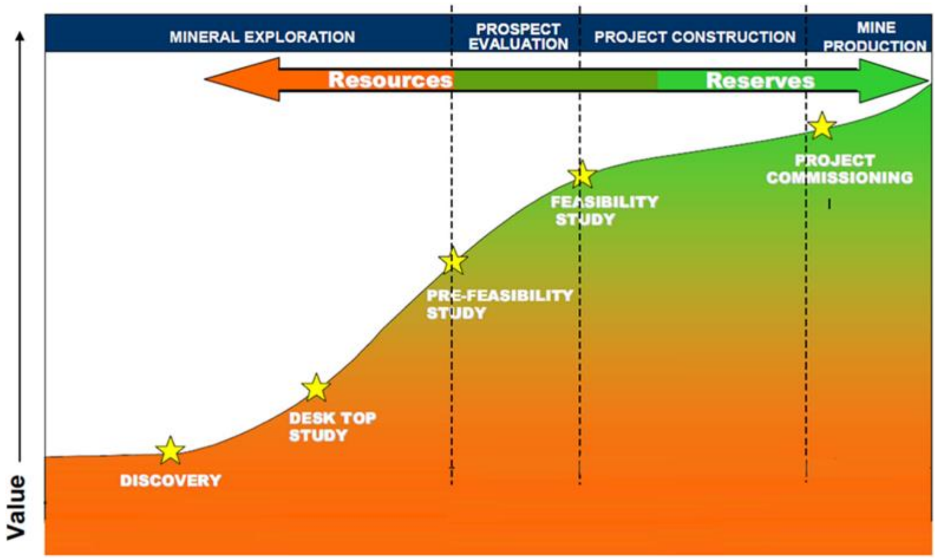

Figure 2-2: The Inter-Relationship of Increasing Certainty and Project Value with Advancing Development Stages and the Level of Technical Study (Noppé, 2014)

2.3.2 The Mineral Properties Valuation Frameworks

The valuation of most enterprises is predominantly influenced by their asset base, which includes both assets that can be quickly converted into cash and those evaluated based on projected future earnings. In the case of mining companies, their valuation is mainly driven by the value of their assets and ongoing projects. This valuation primarily reflects the prospective worth of their mineral deposits, assuming they can be economically extracted in the future, as detailed in the previous section. A distinguishing characteristic of mining companies, as opposed to industrial firms, is the necessity for exploration to discover and define an economically viable resource upon which a mining venture can be established. The likelihood of success in exploration endeavors is relatively low (Rudenno, 2009). Mining companies must secure substantial capital following successful exploration to advance projects and capitalize on mineral resources (Rendu, 2000).

The primary purposes of conducting mineral property valuations are as follows (Lilford, 2010):

(i) Mergers, sales of mineral assets, fairness and reasonableness assessments governed by stock exchanges, and independent expert evaluations designed to safeguard minority shareholders, which may include legal proceedings involving valuation specialists as expert witnesses;

(ii) Financial security prerequisites for debt agreements or derivative financing as stipulated by financial institutions;

(iii) Expropriation issues related to legislative modifications, claims of dispossession, and insurance claims;

(iv) Accounting purposes; and

(v) Initial public offerings (IPOs), new listings, and other equity-raising activities such as rights issues, private placements, and management buyouts.

According to the CIMVAL Code (2019), as outlined in Section 2.3.1 concerning the stages of mineral property development and the valuation frameworks discussed in Section 2.2, suitable valuation approaches corresponding to the categories of mineral properties are detailed in Table 2.1.

Table 2-1. Valuation Approaches for Different Types of Mineral Properties (CIMVAL Code, 2019)

Valuation Approach	**Exploration Properties**	**Mineral Resource Properties**	**Development Properties**	**Production Properties**
Income Approach	No	In Some Cases	Yes	Yes
Market Approach	Yes	Yes	Yes	Yes
Cost Approach	Yes	In Some Cases	No	No

These valuation and mineral classification frameworks and how they can be used for mineral properties are the main questions that may arise when valuing mineral properties. For this reason, international standards have been created. International standards establish a uniform framework for investors and enhance the quality of information disseminated (Rendu, 2000). Globally recognized reporting codes for mineral resources and reserves, such as the JORC Code (Jorc, 2012), SAMREC Code (SAMREC, 2016), and Canadian National Instrument 43-101 (Canadian Securities Administration, 2011), contribute to the transparency, consistency, and technical reliability of feasibility reports. To further this, it is essential to improve the communication of projected project risks to both internal and external stakeholders. This will ensure that reports offer a clearer and more dependable foundation for understanding the potential challenges and uncertainties associated with the project (Noppé, 2016). These kinds of requirements provide more transparent data for investors to benchmark projects.

From this perspective, the mineral resource and reserve reporting codes has paramount importance in the mining industry to increase the reliability of the exploration data because they are based on depleting resources. Therefore, the industry must communicate to build the necessary level of trust and support for its activities; it is essential to communicate investment-related risks both effectively and transparently. Accordingly, CRIRSCO (Committee for Mineral Reserves International Reporting Standards) was formed in 1994 to contribute to earnings and maintain the trust by promoting high standards of reporting of mineral deposit estimates (Mineral Resources and Mineral Reserves) and exploration progress (Exploration Results). Current members of CRIRSCO are Australia, Brazil, Canada, Chile, Colombia, Europe, India, Indonesia, Kazakhstan, Mongolia, Russia, South Africa, Turkey, and the USA (Figure 2.3 and Table 2.2).

These standards aim to create a common language, facilitate communications between investors and companies, and standardize and improve the quality of the information shared with investors. Investors, international agencies, and regulators carefully examine data representation on what is discovered with reliable confidence and standards of the information by international resource reporting codes and standards.

Table 2-2: The International Mineral Resource and Reserve Reporting Standards (CRIRSCO, 2024)

CRIRSCO Members	Reporting Codes	Latest Edition
Australasia	JORC Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves	2012 Edition
Brazil	CBRR Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves	2016 Edition
Canada	The CIM Definition Standards for Mineral Resources and Reserves	2014 Edition
Chile	Commission Minera Code for Reporting of Exploration Results, Mineral Resources, and Mineral Reserves	2015 Edition
Colombia	CCRR Colombian Standard for the Public Reporting of Exploration Results, Mineral Resources and Reserves	2018 Edition
Europe	PERC Pan-European Code for Reporting Exploration Results, Mineral Resources and Reserves	2021 Edition
India	IMIC Indian Mineral Industry Code for Reporting Exploration Results, Mineral Resources and Mineral Reserves	2019 Edition
Indonesia	KCMI Exploration Results, Mineral Resources and Mineral Reserves	2017 Edition
Kazakhstan	KAZRC Kazakhstan Code for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves	2016 Edition
Mongolia	MPIGM Mongolian Code for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves	2014 Edition
Russia	NAEN Russian Code for the Public Reporting of Exploration Results, Mineral Resources, Mineral Reserves	2013 Edition
South Africa	SAMCODES South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves	2016 Edition
Turkey	UMREK National Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves Code of Turkey	2018 Edition
The USA	SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves	2017 Edition

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Figure 2-3: Current Members of the CRIRSCO (CRIRSCO, 2024)

The evolution of international codes and standards for resource and reserve reporting has witnessed several significant milestones, listed chronologically as follows:

- 1988: The Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves (JORC Code) was introduced and incorporated into the Australasian Stock Exchange (ASX) listing rules in July 1989.
- 1990: Guidelines to the Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves were published.
- 1991: The US Society for Mining, Metallurgy, and Exploration (SME) released a Guide for Reporting Exploration Information, Resources, and Reserves. Additionally, the Institution of Mining and Metallurgy in the UK revised its standards for reporting mineral resources and reserves.
- 1994: The Fifteenth Congress of the Council of Mining and Metallurgical Institutions (CMMI) convened a meeting to discuss international standards.
- 1996: The United Nations published the International Framework Classification for Reserves/Resources - Solid Fuels and Mineral Commodities.
- 1999: The Toronto Stock Exchange and the Ontario Securities Commission issued "Setting New Standards: Recommendations for Public Mineral Exploration and Mining Companies," and the SME accepted a revised Guide

for Reporting Exploration Information, Mineral Resources, and Mineral Reserves.

- 2000: The South African Code for Reporting of Mineral Resources and Mineral Reserves (SAMREC Code) came into effect.

The valuation of mineral properties is based on this mineral resource and reporting codes because of worldwide recognition and acceptance of market-related and financial investment. Mineral assets are valued for several reasons, including mergers and acquisitions, pricing of an initial public offering of stock, support for property agreements, litigation, expropriation, and insurance claims (CSA Global, 2019). In all cases, valuation codes ensure complete, accurate, and consistent reporting of information and estimates (Abergel, 2014).

Mineral or mineral property valuation is defined as the estimation of the value of mineral property in money or monetary equivalent (IMVAL Template Third Edition, 2018). Also, the International Mineral Valuation Committee (IMVAL) Template clearly separates valuation from evaluation. Evaluating a mineral property involves a thorough examination of physical, technical, legal, economic, and other relevant factors, usually aimed at guiding investment decisions. This process includes feasibility studies, pre-feasibility studies, preliminary economic assessments, technical assessments, and scoping studies. It is crucial to distinguish that evaluation is not the same as valuation. In a manner analogous to resource and reserve reporting codes, key milestones in the development of codes or standards for the valuation of mineral properties are outlined chronologically as follows (IMVAL Template Fourth Edition, 2021):

- The Australasian VALMIN Code, now known as the Australasian Code for Public Reporting of Technical Assessments and Valuations of Mineral Assets, was initially adopted by The Australasian Institute of Mining and Metallurgy (AusIMM) in February 1995. This code has undergone several revisions, with the most recent update published in 2015.

- In early 2001, the International Valuation Standards Council (IVSC) established an Extractive Industries Task Force comprising international experts in mining and petroleum industry valuation.
- The Canadian Institute of Mining, Metallurgy and Petroleum (CIM) adopted the CIMVAL Standards and Guidelines for the Valuation of Mineral Properties in February 2003. This was succeeded by an updated CIMVAL Code for the Valuation of Mineral Properties, which was ratified by the CIM Council on November 29, 2019, replacing the 2003 version.
- The IVSC's Guidance Note 14 (GN 14), titled "Valuation of Properties in the Extractive Industries," was first published in January 2005 as part of the IVS Seventh Edition and republished in the Eighth Edition in 2007. The IVSC Standards Board withdrew GN 14 in February 2010.
- The South African SAMVAL Code, known as The South African Code for the Reporting of Mineral Asset Valuation, was developed by a Working Group under the SAMCODES Standards Committee and was first published in April 2008. It was amended in July 2009, and an updated version was released in 2016.
- In April 2012, discussions in Brisbane aimed to establish a harmonization project for the mineral valuation codes VALMIN, SAMVAL, and CIMVAL, and where applicable, USPAP, the IVSs, and IFRSs (International Financial Reporting Standards).
- The International Mineral Valuation Committee (IMVAL) was formed in July 2012 to develop a mineral asset valuation template, following the framework of the International Reporting Template of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO).
- The IMVAL Template was first published in July 2016; a third version was released in 2018.
- The USA-based Society for Mining, Metallurgy, and Exploration, Inc. (SME) released its first edition of the SME Valuation Standards in January 2016. The USA-based International Institute of Mineral Appraisers (IIMA)

adopted the Second Edition of the Template in 2015 and later formally adopted the Third Edition.

- The First and Second Editions of the IMVAL Template referenced the IVSs 2013 edition, while the Third Edition referenced the IVSs 2017 Edition. The Fourth Edition of the IMVAL Template has been updated to align with the IVSs effective from January 31, 2022.

Before the development of the IMVAL Template, only three national codes or standards, the Australasian VALMIN Code, the Canadian Institute of Mining, Metallurgy and Petroleum CIMVAL Code, and the South African SAMVAL Code, were available for the valuation of mineral properties. These codes have many similarities but differ in structure, definitions, scope, and jurisdictional requirements. In addition to these codes, the International Valuation Standards (IVSs) and the USA's Uniform Standards of Professional Appraisal Practice (USPAP) also contain valuation standards of general application non-specific to mineral property valuation.

At this point, the purpose of the IMVAL Template is to develop a common set of minimum requirements for those codes or standards for the valuation of mineral properties. Valuations and Valuation Reports require three fundamental principles, Competence, Materiality, and Transparency, in addition to three supportive principles, Objectivity, Independence, and Reasonableness.

Competence is defined in Sentence 50 of the IVS framework as given below. Accordingly, a Valuer who is not personally competent enough to undertake an aspect of a Valuation assignment must seek assistance from an Expert who is competent in the applicable field or discipline necessary to address that aspect. Material assistance from Experts must be disclosed in the Valuation Report.

> *"Valuations must be prepared by an individual, group of individuals, or individual within an entity, regardless of whether employed (internal) or engaged (contracted/external), possessing the necessary qualifications, ability and experience to execute a valuation in an objective, unbiased, ethical and competent manner and having the appropriate technical skills,*

experience and knowledge of the subject of the valuation, the market(s) in which it trades and the purpose of the valuation.”

Materiality means that the Public Report contains all the relevant information that investors and their professional advisors would reasonably require and reasonably expect to find in the report to make a reasoned and balanced judgment regarding the Technical Assessment or Mineral Asset Valuation being reported (VALMIN Code, 2015 Edition). On the other hand, Transparency means that the reader of a Public Report is provided with sufficient information, the presentation of which is clear and unambiguous, to understand the report and not be misled by this information or by omission of Material information (VALMIN Code, 2015 Edition).

There exists a body of knowledge in the literature and established valuation principles in the broader field of valuation that, while not explicitly addressing the valuation of mineral properties, are applicable to it. Several of these fundamental valuation principles, which are essential for accurately estimating value, are outlined as follows (CIMVAL Code, 2019):

i. Value pertains to a specific point in time, and valuation opinions must clearly specify the valuation date.
ii. Value is determined based on current and future expectations.
iii. The value of an asset is derived from, or directly related to, its earning potential.
iv. Hindsight generally should not be used when forming valuation conclusions.
v. The market dictates the required rate of return.

These three approaches have several methods for general or specific use for mineral properties. Valuation methods are generally subsets of these approaches. Table 2 3 presents valuation methods commonly used for valuing mineral properties. The following subsections will explain some critical valuation methods for valuing mineral properties.

Table 2-3. Valuation Methods (CIMVAL Code, 2019)

Valuation Approach	Valuation Method	Ranking
Income	Discounted Cash Flow	Primary
Income	Real Options	Primary
Market	Comparable Transactions	Primary
Market	Option Agreement Terms	Primary
Market	Market Capitalization	Secondary
Cost	Appraised Value	Primary
Cost	Multiple of Past Exploration Expenditure	Primary
Other	Geoscience Factor	Secondary

2.3.2.1 Discounted Cash Flow Methods

The Discounted Cash Flow analysis is an intrinsic value approach in which a business's value is the value of all expected cash flows, discounted with a discount rate appropriate for the project. In discounted cash flow analysis, analysts forecast a project or asset's unleveraged free cash flow into the future. Then, the Weighted Average Cost of Capital (WACC) discounts it back to the present. The unlevered free cash flow, commonly referred to as Free Cash Flow to the Firm (FCFF), represents the cash flow available to both equity holders and debtholders after accounting for all operating expenses, capital expenditures, and investments in working capital. This measure is employed in financial modeling to estimate the enterprise value of a company or project. The Unlevered Free Cash Flow is calculated using Equation 2.1 (CFI, n.d).

$$\text{UFCF} = \text{EBIT} - \text{Taxes} + \text{D\&A} - \text{CapEx} - \text{Increase in NonCash Working Capital} \tag{2.1}$$

The rationale behind using unlevered free cash flow is to eliminate the influence of capital structure on valuation, thereby enhancing comparability. There are two primary reasons for neutralizing the impact of capital structure in valuation. Firstly, it facilitates comparability among firms or projects by excluding interest expenses and recalculating taxes, enabling a more direct comparison. Secondly, capital structure is often discretionary, influenced by decisions made by the company's owners or managers regarding financing choices.

When considering the detailed calculation of unlevered free cash flow, the initial component of the formula is EBIT, which stands for Earnings Before Interest and Taxes. EBIT is derived by subtracting all operating expenses from sales revenue, which is why it is commonly referred to as operating income. EBITDA stands for earnings before interest, taxes, depreciation, and amortization. EBIT can be computed using Equation 2.2 (CFI, n.d):

$$\begin{aligned} &\text{EBIT} = \text{Net Income} + \text{Taxes} + \text{Interest Expense OR} \\ &\text{EBIT} = \text{EBITDA} - \text{Depreciation and Amortization Expense} \end{aligned} \tag{2.2}$$

The second component of unlevered free cash flow involves taxes, computed based on the applicable rules and regulations in the country where the project or asset is situated. Various methodologies for tax calculation may be employed depending on the jurisdiction.

The third element of unlevered free cash flow is Depreciation and Amortization Expenses. Property, Plant, and Equipment (PP&E) represent non-current, tangible capital assets essential for revenue generation and profit, such as trucks and excavators utilized in mining operations. When a company acquires new equipment for production purposes, the net value of PP&E gradually diminishes annually due to depreciation. Depreciation allocates the reduction in asset value over time due to wear and tear, reflecting the asset's expected useful life and its ability to generate returns beyond the initial accounting period. Therefore, a depreciation process is employed to align the expense of a long-term asset with the periods during which it provides benefits or generates revenue. Several methods exist for calculating depreciation, with the choice of method typically influenced by the nature of the equipment and the specific industry context.

There are four common methods used for calculating depreciation. Those are

1. Straight Line Depreciation
2. Declining Balance (Accelerated Depreciation)
3. Units-of-Production
4. Sum of Years Digits

The straight-line depreciation method is widely utilized and considered the simplest approach for calculating depreciation. Under this method, an equal amount of depreciation expense is recognized each year throughout the asset's useful life. The formula for the straight-line depreciation method is as follows (CFI, n.d):

$$\begin{aligned}&\text{Periodic Depreciation } = \\ &(\text{Initial Book Value} - \text{ Salvage Value}) \,/\, \text{Useful Life of Asset}\end{aligned} \tag{2.3}$$

The declining balance method, also known as accelerated depreciation, is often employed to depreciate assets more rapidly in the initial years following investment. In the declining balance depreciation method, Equation 2.4 can be used.

$$\begin{aligned}&\text{Periodic Depreciation } = \\ &\text{Remaining Book Value x } (1/\text{ Useful Life of Asset})\end{aligned} \tag{2.4}$$

Unit-of-Production depreciation method depreciation expense per unit produced is calculated by dividing the historical value of the asset minus the residual value by its useful life in terms of units. It is the most useful method for depreciating production machinery, such as excavators used in the mining industry. Equation 2.5 can be used for the unit-of-production depreciation method (CFI, n.d):

$$\begin{aligned}&\text{Periodic Dep. Exp.} = \text{ Unit Depreciation Expense } * \text{ Units Produced} \\ &\text{where} \\ &\quad \text{Unit Dep. Exp.} = (\text{Book Value} - \text{ Salvage Value}) \,/\, \text{Useful Life in Units}\end{aligned} \tag{2.5}$$

The sum-of-the-years'-digits (SYD) depreciation method allocates the asset's depreciable amount based on a depreciation factor specific to each year. The depreciable amount is calculated as the asset's total acquisition cost minus its salvage value. The total acquisition cost represents the total capital expenditure incurred by the company to acquire the asset.

$$\begin{aligned}&\text{Sum of year depreciation } = (\text{n}/\textstyle\sum\text{n}) * \text{Depreciable Amount where} \\ &\text{N is the useful life of the asset} \\ &\textstyle\sum\text{n is the sum of years} \\ &\text{Depreciable Amount is the Total Acquisiton Cost} - \text{ Salvage Value}\end{aligned} \tag{2.6}$$

The fourth component of unlevered free cash flow is Capital Expenditures, which refers to the capital allocated by a company for acquiring, maintaining, or enhancing fixed assets such as properties, equipment, and factories.

The fifth component of unlevered free cash flow is the Increase in Non-Cash Net Working Capital. Non-cash working capital denotes the capital utilized by businesses to finance their operations, excluding liquid cash. It can be computed using Equation 2.7 (CFI, n.d).

$$\begin{aligned} &NonCash\ Working\ Capital \\ &\quad = Current\ Assets\ without\ Cash - Current\ Liabilities\ OR \\ &NonCash\ Working\ Capital \\ &\quad = Accounts\ Receivable + Inventory - Accounts\ Payable \end{aligned} \tag{2.7}$$

Another critical aspect to consider in Discounted Cash Flow (DCF) analysis is the Weighted Average Cost of Capital (WACC). WACC represents the composite cost of capital from various sources, including common shares, preferred shares, and debt. Each component's cost is weighted according to its proportion of the total capital structure and aggregated together. The cost of capital signifies the minimum rate of return that a business must achieve to create value. In financial modeling, WACC serves as the discount rate for computing the net present value of a project or business. WACC is computed using Equation 2.8:

$$\begin{aligned} \text{WACC} &= \text{Cost of Equity} * \%\ \text{Equity} + \text{Cost of Debt} * \%\ \text{Debt} * (1 \\ &\quad - \text{Tax Rate}) + \text{Cost of Preferred Stock} * \%\ \text{Preferred Stock} \end{aligned} \tag{2.8}$$

The initial component of WACC is the cost of equity, determined through the Capital Asset Pricing Model (CAPM), which aligns rates of return with volatility (risk versus reward). The formula employed to compute the cost of equity is given in Equation 2.9 (CFI, n.d).

$$
\begin{aligned}
&Re = Rf + \beta \times (Rm - Rf)\\
&\text{Where:}\\
&Rf = \text{the risk} - \text{free rate (typically the 10}\\
&\qquad\qquad - \text{year U.S. Treasury bond yield)} \qquad (2.9)\\
&\beta = \text{equity beta (levered)}\\
&Rm = \text{annual return of the market}
\end{aligned}
$$

The cost of equity represents an implicit or opportunity cost of capital, reflecting the rate of return that shareholders expect to compensate for the risk of investing in the stock. Beta measures the volatility of a stock's returns relative to the broader market. The risk-free rate represents the return from investing in a risk-free security, such as U.S. Treasury bonds. Generally, the yield on 10-year U.S. Treasury bonds is the standard benchmark for the risk-free rate.

The second component of WACC comprises the costs associated with debt and preferred stock. The cost of debt is calculated using the yield to maturity on the firm's debt, while the cost of preferred stock is determined by the yield on the company's preferred shares. These costs are subsequently weighted according to their respective proportions within the company's capital structure.

2.3.2.2 Comparable Transactions Method

The comparable transactions method enables the estimated value of a mining project to be compared against established market values of similar mining projects. This method ensures that valuation estimates align closely with actual market transactions. It involves using transaction prices of comparable properties to evaluate the property's value undergoing valuation.

The following factors are the determinative factors for the value of property.

(i) Potential for the existence and discovery of an economic deposit,

(ii) Geological attributes such as ore grade and impurities exist on ore body,

(iii) Mineralization, exploration results, and targets, nearby exploration potential,

(iv) Infrastructure of property,

(v) Area and location of the property,

(vi) Granted and existing permits.

This method is a benchmark for appraising development and producing properties to ascertain the asset's intrinsic value. Comparable transactions also incorporate market factors such as reserves and other risks. The market value of a mining company's project(s) (measured as Asset Market Capitalization (AMC) or Enterprise Value (EV)) is determined by the market capitalization of the company that owns the project(s) (see Equation 2.10).

$$\begin{aligned}
&\text{Implied market value of mining projects (AMC or EV)} = \\
&+ \text{Company market capitalization} \\
&- \text{Working capital} \\
&- \text{Value of other investments} \\
&+/- \text{Value of hedge book} \\
&+ \text{Liabilities} \\
&(+ \text{Capital to production})
\end{aligned} \tag{2.10}$$

The parameters listed in Table 2.4 can also be used for comparable project parameters and market valuation of a comparable project.

Table 2-4: Parameters for Relative PV Valuation (Baurens, 2010)

Comparable Project Parameters	Market Valuation Ratio
Geological Resource	AMC / oz resource
Mineable Reserve	AMC / oz reserve
Operating Cash Flow	AMC / EBITDA
Cash Flow After Capital	AMC / EBIT
Net Cash Flow	AMC / NCF
Net Present Value	AMC / NPV

2.3.2.3 Appraise Value Method

The Appraised Value Method operates on the principle that the true value of an exploration property or a marginal development property is contingent upon its potential to contain an economically viable mineral deposit. This method assumes a direct relationship between the value of exploration expenditures and the property.

The appraised value is computed as the cumulative historically significant exploration expenses and justified future expenditures. These future costs cover a reasonable exploration budget to evaluate identified potential mineral resources. The Appraised Value Method is most effectively applied to actively explored properties. Its application becomes more challenging for properties that have remained inactive for extended periods, particularly those with substantial historical expenditure.

2.4 Factors Effective in Decision-Making Process of an Investment for a Mineral Property

An investor’s decision is influenced by the anticipated costs, the individual's familiarity with advanced techniques, and their subjective perception of risk. An investor wants to know the pay-off period. The decision to proceed with an investment depends on evaluating whether to commit to the expenditure (Harcourt et al., 1967). To make a proper investment decision, the investor must thoroughly and accurately comprehend all potential opportunities, avoiding hasty decisions that could result in significant financial losses or even bankruptcy. Understanding the fundamental principles of investment decisions is crucial for maximizing value from the appraisal process. In investment evaluation, the selection of indicators should be tailored to the specific characteristics of the project and the information available to the decision-maker (Avram et al., 2009).

Investment involves allocating resources over the medium or long term to recover costs and achieve substantial profits. Apart from financial resources, the availability of material and human resources remains critical throughout the duration of the investment. Economic and financial conditions significantly influence investments, introducing uncertainty regarding anticipated outcomes (Avram et al., 2009). Consequently, investment decisions necessitate comprehensive project analysis. Among the pivotal factors influencing these decisions is the investment's inherent risk. This risk comes from considerable uncertainties, particularly concerning the timing of cost recovery (payback period) and the net profits realized over time.

The evaluation of a mining company with an investment view depends upon many factors relating to the company itself, its relative comparison with its peers, and the type of investor considering a purchase. One of the initial questions asked by some potential investors in a company is who the management is and what experience they have in running a mining operation.

A distinctive characteristic of the mining industry is the necessity to conduct exploration to discover and delineate an economically viable resource upon which a mining project can be established. The success rate for exploration endeavors is relatively low, requiring companies to invest substantial amounts of risk capital (exploration funds) well in advance of the potential development of a revenue-generating project (Rudenno, 2012).

Historically, valuations in the mining sector have shown a strong correlation with commodity prices, more so than in other capital-intensive industries. Mining market capitalizations exhibit a 93 percent correlation with commodity prices, compared to 84 percent for oil and gas, 64 percent for steel, and 60 percent for pulp and paper (World Bank, 2020). Commodity prices are known for their cyclical nature, and mining has experienced five such cycles since 2000. It is anticipated that future cycles will continue to exhibit similar cyclicity with increased volatility, driven by declining ore grades and worsening mine conditions, which lead to higher operating costs and a steeper cost curve. This cyclicity presents challenges for mining companies in securing financing, given the volatility in valuations and the cyclical nature of capital expansion (Mareels et al., 2020).

Sensible valuation of mineral properties has become more vital in the current market cycle. Valuing mineral properties at the exploration stage presents challenges and uncertainties that both appraisers and stakeholders must comprehend. As defined in Section 2.3, an exploration property refers to an area where an economically viable mineral deposit has not yet been discovered. Consequently, the asset values of exploration properties are derived from their potential to yield economically viable mineral deposits through discovery.

Valuing exploration projects that lack defined resources is complex due to the need to account for both technical and market factors. Technical considerations include the geological understanding of the project area, the style of targeted mineralization, and the distribution and scale of mineralization indicators identified from previous exploration activities (e.g., geochemical or geophysical data). Market factors involve recent comparable transactions, geographic location, infrastructure costs, and prevailing commodity prices.

The risks associated with international investing can generally be categorized into financial, economic, and political risks. Financial risks primarily involve issues directly related to monetary concerns, such as loan defaults or difficulties in repatriating profits to the home country. Economic risks encompass factors such as economic volatility, reflected in current and anticipated inflation rates, the current account balance relative to goods and services, restrictive regulations, and labor laws. Political risks include elements like government instability, expropriation, bureaucratic inefficiency, corruption, and potential conflict or war (Harrington et al., 2021).

In addition to the risks associated with international investment, mineral properties present inherent risks and uncertainties. These include permitting risk, geological risk, and geographic risk. Clearly defining these risks is essential to mitigate uncertainty levels in mining investments. Therefore, the current study will use the system dynamics method for thorough risk assessment.

2.5 System Dynamics Method

The current study will employ system dynamics modeling to examine the decision-making processes involved in mining investments. System dynamics, an advanced methodology for quantitatively modeling complex feedback structures, was developed by Jay Forrester in the mid-1950s. Its primary aim is to elucidate intricate dynamic systems and enhance decision-making in response to the challenges presented by these systems (Forrester, 1961). This approach is applicable to dynamic issues within complex social, managerial, economic, or ecological systems. System dynamics facilitates the representation and analysis of complex systems by simulating and observing behavioral patterns over time. The subsequent section will explore the definitions, theory, and terminology associated with system dynamics.

2.5.1 Definitions and Theory

System dynamics is a modeling technique grounded in the principles of systems thinking. This approach emphasizes understanding how elements interact as a whole rather than viewing problems in isolation from other components (Sterman, 2001). Anderson and Johnson (2007) delineated five core principles of this methodology:

i. It considers the big picture and takes a step back to broaden the perspective of the root cause of the problems.
ii. It creates a balance between the long-term and short-term perspectives (e.g., rather than searching for the solution in the nearest causality, focusing on the other elements and their interrelationships as well)
iii. It helps to understand different systems' dynamic, complex, and interrelated nature.
iv. It involves both measurable and immeasurable elements of the system in analysis.
v. It always considers the perspective of the modeler and its position in the system and its surrounding environment.

These philosophies of systems thinking are integral to system dynamics, which has been further developed as a simulation technique. According to Sterman (2000), the initial step in system dynamics (SD) modeling involves understanding the system concerning the problem statement and defining its boundaries. Despite variations in system definitions, a system is generally recognized as a collection of interconnected parts (components, elements) organized within defined boundaries and serving a common purpose, such as a physical process, an organization, or even a country (Waring, 1996; Yim et al., 2004). The synergy among system elements, which evolves over time, underscores the importance of accurately defining the system's boundaries. The interactions of these components within the defined boundary outline the system's structure (Yim et al., 2004). The system dynamics process can be summarized in five key steps, as illustrated in Figure 2.4.

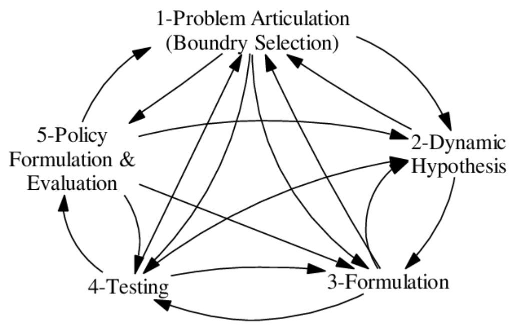

Figure 2-4: Iterative and Feedback Process of Modeling based on System Dynamics Methodology (Sterman, 2000)

Step 1: Define the research objective to initiate the system dynamics problem. Identify key factors, distinguishing those to be included from those to be excluded, and establish the relevant system boundaries. Additionally, determine the hypothesized behavior of the problem and the time horizon of interest.

Step 2: Develop a dynamic hypothesis and construct causal loop diagrams and/or stock and flow diagrams to illustrate the system's structure and relationships.

Step 3: Complete the simulation and formulation of the model.

Step 4: Test the model to evaluate the feasibility and accuracy of its structure. Assess the sensitivity of various feedback loops, as they generally exhibit greater variability than parameters. The model's flexibility enables testing of different structures and parameter sensitivities, which helps to determine the effort needed to enhance parameter accuracy.

Step 5: Conduct policy analysis and design once a reasonable and rational level of confidence in the model has been achieved.

System dynamics models can be developed through causal-loop diagrams as a qualitative approach or stock and flow diagrams as a quantitative approach. This study will utilize stock and flow diagrams to explain the decision-making stages quantitatively.

In stock and flow diagrams, stocks represent the outcomes of accumulations over time (Figure 2.5). These values indicate the accumulation level, also called states, collectively representing the system's condition at time t. Examples of stocks include cash balances, production quantities, and other measurable accumulations. On the other hand, flows directly affect the levels of stocks by entering and exiting them, thereby altering their accumulations. Flows represent the 'rate of change' of stocks. Examples of flows include income and expenses, production, and sales rates. The units of these rates must be defined as units per time (e.g., dollars per month, barrels per day). This characteristic enables stocks to accumulate over time.

Figure 2-5: A Schematic view of a simple stock and flow diagram

While stocks and flows are essential for generating dynamic behavior, they are not the sole constituents of dynamic systems. Specifically, stocks and flows are integral parts of feedback loops within real-world systems, where these loops are frequently interconnected through nonlinear couplings that can lead to counterintuitive behaviors. The following sections will provide various examples of system dynamics models developed specifically for financial investment decisions and mining-related scenarios.

2.5.2 Implementation of System Dynamics for Financial Investments

This section summarizes some related financial investment studies employing system dynamics methodology. Nair and Rodrigues (2013) employed a stock and flow system dynamics model to simulate various financial parameters such as the net cash flow, gross income, net income, pending bills, receivable bills, debt, and book value to understand the financial health of an organization during the expansion of production capacity in the electronics industry (Figure 2.6). Notably, debt and book value exhibited a nonlinear pattern of variation, which is discussed in detail. The model is a decision-support tool for financial experts to derive conclusions regarding organizational expansion plans. Additionally, the system dynamics model has been utilized to analyze factors related to changes in scope resulting from technological advancements.

The chosen system dynamics scenario for analysis in the study involves a hypothetical electronic system manufacturer aiming to increase annual production from approximately 1100 units to an expected 8000 units over the next five years. The company plans to achieve this through an annual production growth rate ranging from 10% to 40%, facilitated by augmenting production equipment. The study aims to simulate the financial dynamics, focusing on specific variables of interest.

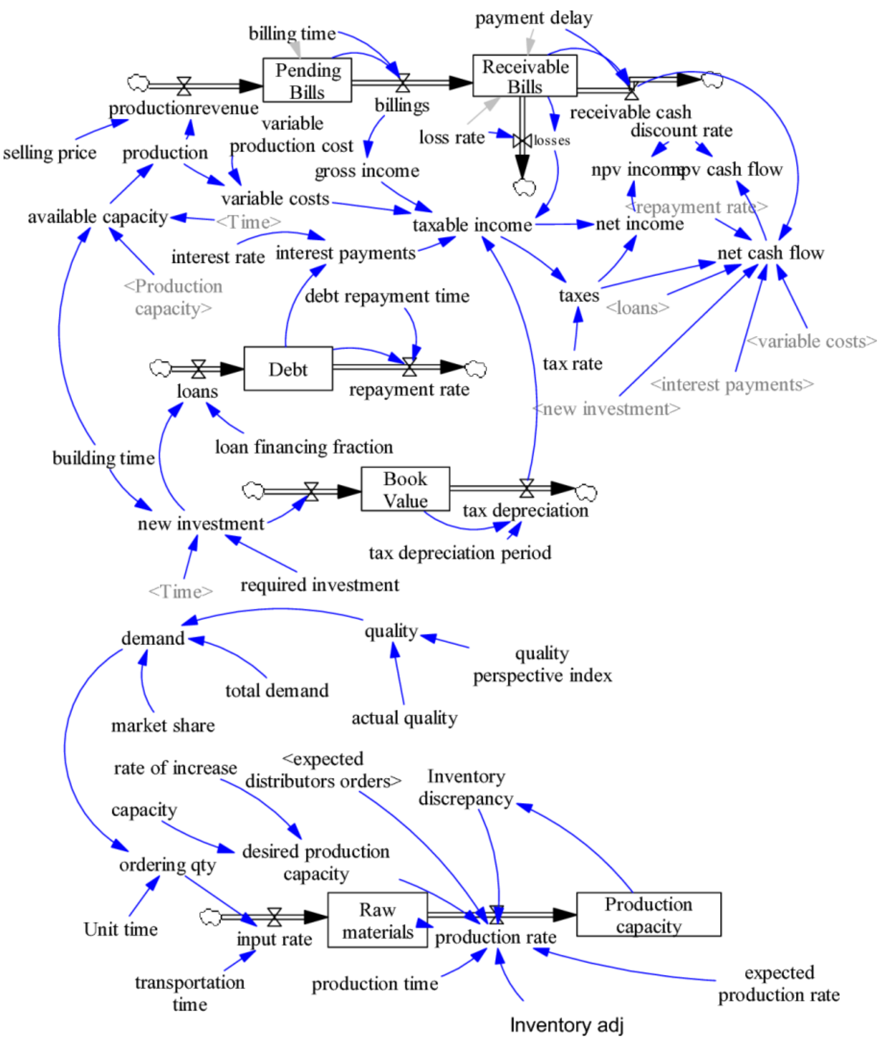

Figure 2-6: The Stock and Flow of Financial Dynamics (Nair and Rodrigues, 2013)

Fernandez et al. (2014) constructed a causal loop diagram to evaluate asset investment according to the desired return on assets. The model parameters are grouped according to the evaluated sector. They were employed in the sector analysis of gross profit-associated parameters used for one year in a related finance company lending and deposit rates. The results are focused on two possible scenarios framed to analyze the yield of the desired state. The first stage is when the return on assets increases the investment demand. The second is when the desired return on assets becomes less than those accumulated systems. In conclusion, the growth of the financial sector shows the importance of researching and planning the resources needed to develop their activities. It allows the system dynamics to examine the behavior in time of the associated financial models and how they fail to understand the policies to adopt in their planning and monitoring, which may produce more significant benefits to provide growth companies not only in the banking sector and which have similar characteristics to those studied.

Zherlitsyn et al. (2021) developed a conceptual model for the financial logistics of a company using system dynamics principles. This model is guided by strategic objectives, particularly the maximization of gross revenues or operational profit. To address the operational destabilization of key strategic indicators, the model emphasizes the need to study and optimize the dynamics of gross profit by analyzing revenues (by activity type), costs (including operating leverage, logistics costs, and time delays), and working capital turnover, average costs, and working capital leverage. The investment and financial subsystems of the model offer insights into the dynamics of capital (such as the weighted average cost of capital and profitability) and profit (including financial leverage, net gain or loss, penalties, and regulatory costs). The causal diagram illustrating the relationships within the financial logistics model is depicted in Figure 2.7, reflecting the specified aspects of financial flow management processes and the system-dynamic simulation methodology (Bala et al., 2017; Broy, 2014).

Fan et al. (2007) developed a system dynamics model that integrates factors such as investment in the coal industry, available reserves, mine construction, and coal supply capabilities. The model also explores the effects of investment in state-owned mines and geological prospecting. The model simulated the behavior of the entire coal system influenced by mine investment, analyzed its impact on the coal sector, and forecasted coal production capacity under different scenarios for the year 2020.

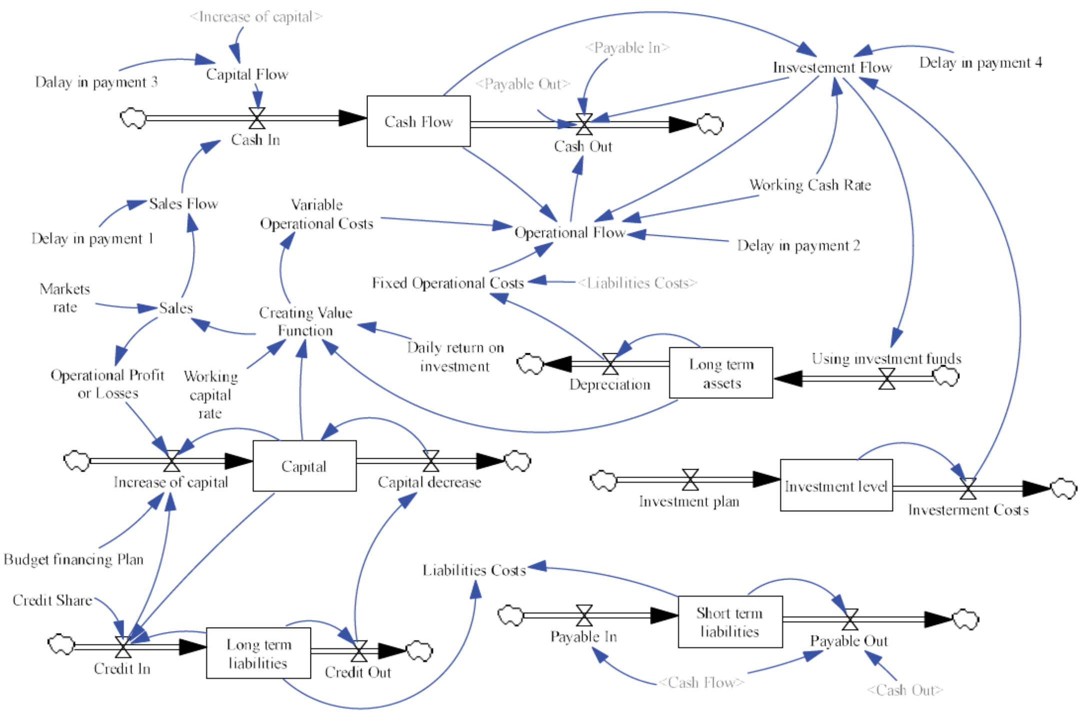

Figure 2-7: Company Financial Logistics (Zherlitsyn et al., 2021)

Liu et al. (2019) introduce a hybrid investment evaluation framework integrating real options and system dynamics specifically for mining projects. This model addresses uncertainties and managerial flexibilities inherent in mining ventures by combining the static net present value derived from traditional discounted cash flow analysis with the real options value computed using the Black-Scholes model. Subsequently, system dynamics modeling is employed to discuss the dynamic complexities of mining operations, quantify variables and interactions, and estimate volatility to enhance the accuracy of real options valuation. The Hongwei uranium deposit in China is utilized as a realistic case study to illustrate the model numerically.

Liu et al. (2019) employ a system dynamics simulation model to analyze cash flow changes in mining projects. Their study integrates both qualitative and quantitative analyses. Qualitatively, they observe that increasing production capacity results in substantial investments, which impose adverse burdens on mining operations.

Specifically, they evaluate the Hongwei uranium deposit using their proposed method. The analysis indicates that the project, valued at 175.59 million yuan using the traditional Discounted Cash Flow (DCF) method, would have been rejected. However, factoring in uncertainties and managerial flexibility, the project's valuation rises to 576.50 million yuan, confirming its economic feasibility. Their approach enhances the accuracy of mining project valuations, aiding decision-makers in making informed investment choices.

Roodsari (2022) conducted a study on simulating an investment decision system using the System Dynamics (SD) approach, aiming to assist a holding company in selecting appropriate projects based on various criteria. The proposed model comprises four categories of variables: stock, auxiliary, constant, and rate. A stock and flow diagram was derived from causal loop diagrams. Powersim Software was utilized for model simulation. The gathered information facilitated the analysis and exploration of the investment decision system's structure and behavior, aiding in decisions regarding subsidiary company and project investments.

Khan et al. (2022) revealed that exchange rate volatility significantly affects firm value, but its impact remains unclear due to mixed evidence in existing literature. Using a system dynamics-based corporate planning model, this article explores how exchange rate fluctuations influence firm value. The model integrates financial and physical processes with firm valuation and exchange rate determination. Simulation results show that a stronger home currency typically increases a firm's market price per share. The study highlights the non-linear feedback mechanisms of exchange rate impacts, filling a literature gap by offering a systemic approach to analyze how parameter changes affect firm value. By examining an energy firm, Equinor, the study demonstrates the need for a comprehensive model that considers financial and operational elements to accurately assess exchange rate impacts. The findings offer valuable insights for decision-makers, showing how systemic interactions between variables like interest rates and exchange rates affect firm value. The system dynamic modules developed in the study are illustrated in Figure 2.8.

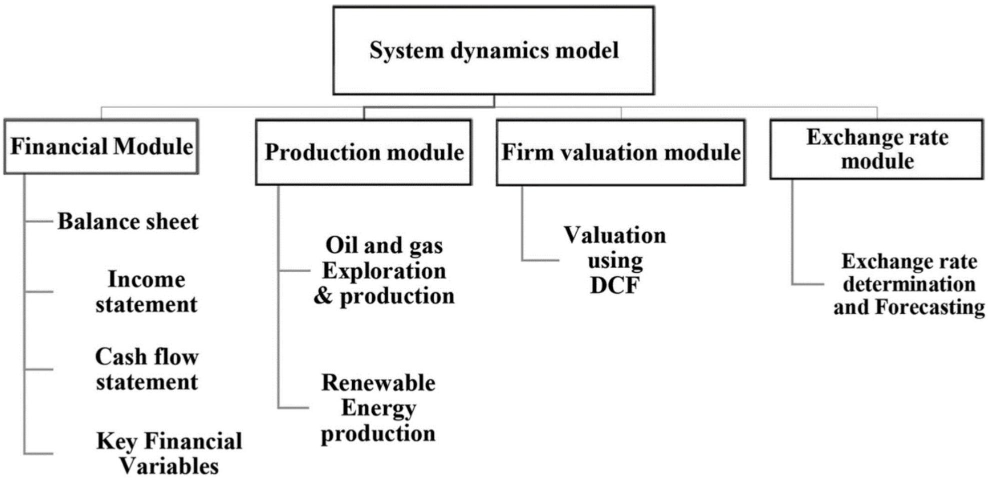

Figure 2-8: The Description of the System Dynamic Models (Khan et al., 2022)

Khan et al. (2023) aimed to enhance firm value through the strategic design of corporate finance policies and scenario analysis to achieve the highest possible firm value in their study. The study constructs a system dynamics model tailored for an oil company, integrating both financial and physical processes to assess firm valuation. This model is tested under various scenarios involving current and alternative investment strategies, capital structures, and dividend policies, with fluctuating oil and gas prices and tax rates, to determine the optimal policy combination for maximizing firm value. Simulation findings indicate that reducing investment volume, increasing debt levels, and cutting dividend payouts from their current levels can boost share prices when oil and gas prices are expected to rise and tax rates are lower. Conversely, increasing investments towards the end of the simulation period results in a higher overall firm value. In lower expected oil and gas prices, decreasing investment volume, debt ratio, and dividend payments can still enhance share prices if taxes are reduced. This study is notable for developing a detailed financial planning model for an oil firm, capturing the complex interactions between critical financial and physical processes. It contributes to corporate finance discussions by integrating various theories, considering accumulation processes, feedback loops, and their nonlinear effects. The research underscores the importance of evaluating the combined impact of different policies on firm value management.

2.6 Summary and Study Motivation

This section builds a comprehensive knowledge base by exploring relevant topics and thoroughly reviewing the literature. Initially, it introduces the concept of emerging markets and distinguishes between emerging and developed markets. Subsequently, it performs detailed discussions on mineral development stages, the framework for mineral classification, international standards for resource and reserve reporting, international valuation standards, and the valuation framework for mineral properties. Then, the literature concentrated mainly on the valuation of mineral properties and investment decision-making supported by system dynamics methodology is discussed. The study's emphasis on a system dynamics decision model for mining investments underscores the importance of mineral property valuation and the challenges in investment decision-making within the mining industry. Due to the high uncertainty at the managerial level in the mining industry investment decision-making and the significant commitment of capital required for project development, careful management of investment decisions is emphasized. Furthermore, the study reveals key concepts such as mineral property valuation, mineral development stages, resource and reserve reporting standards, and valuation at different stages of mineral properties. These concepts are pivotal for implementing the system dynamics model developed in this study as they decide capital allocation toward mineral properties.

Investment decision-making supported by system dynamics models in emerging markets for mineral properties has received limited detailed attention despite various studies on decision-making processes. Additionally, investment decision-making in the mining industry remains constrained despite its potentially significant impact on a company's future. The current research primarily focuses on enhancing the value of mineral properties by analyzing factors influencing valuation. It seeks to address these gaps by developing a system dynamics model for investment decision-making in the mining industry within emerging markets, considering diverse investment criteria. Furthermore, it includes a case study demonstrating the practical implementation of the developed model

CHAPTER 3

DEVELOPMENT OF A SYSTEM DYNAMICS MODEL FOR THE INVESTMENT INVESTIGATION OF A MINERAL PROPERTY

3.1 Introduction

Developing a growth strategy and investment decision-making policy for companies in the mining industry presents significant challenges due to several embedded reasons unique to this sector, as listed below.

i. Mining companies differ from industrial firms regarding the requirement for exploration to discover and delineate economically viable mineral resources necessary for mining projects. The success rate for exploration endeavors is notably low (Rudenno, 2009).

ii. Upon successful exploration, mining companies require substantial capital investment to develop projects to extract and exploit mineral resources to generate wealth (Rendu, 2000).

iii. Mining is an inherently high-risk industry characterized by various risks, including commodity price fluctuations, social impacts, legal and regulatory uncertainties, environmental challenges, technological complexities, and geological uncertainties.

iv. Last, the mining industry relies on the finite depletion of ore reserves, emphasizing its reliance on a depleting resource base.

Given these unique circumstances, investment decision-making becomes a complex process. In the mining industry, this process typically commences with a crucial step known as project evaluation. Project evaluation in mining entails a comprehensive assessment encompassing physical, technical, legal, economic, and other factors relevant to a mineral property, which is crucial for guiding investment decisions. Evaluations typically include scoping studies, technical assessments, preliminary economic assessments, pre-feasibility studies, and feasibility studies. Due to the high-risk nature of mining, investment decisions must assess potential financial returns and account for the uncertainties that could affect these returns, potentially making the investment impractical. Risk assessment in mining investments involves evaluating the likelihood and impact of various potential outcomes. Each stage in the development of a mine carries specific risks that necessitate effective risk management strategies, including assessing the probability of success and implementing measures to mitigate risks.

System Dynamics models integrate theoretically accepted and empirically observed relationships using mathematical equations governed by stocks, inflows, outflows, and auxiliary variables (Sterman, 2000). This approach results in a network of balancing and reinforcing feedback loops that interact to shape the system's behavior. Such models serve as effective tools for corporate planning and policy-making processes, enabling the exploration of various policies and scenarios to enhance understanding of system dynamics and address problematic behaviors. Under the scope of this study, investment decision-making behavior is determined using the system dynamic concept. This modeling type is expected to facilitate the understanding and representation of causal relationships underlying investment decision-making in the mining industry.

3.2 Development of the System Dynamic Model

Several existing models, such as Aima Khan et al. (2019, 2020), were examined in constructing a generic model focusing on investment decision-making in the other industry. However, the developed model incorporates other parameters, such as risk appetite, behavioral decisions, and corporate governance. These factors significantly influence investors' decision-making regarding mineral properties, thereby impacting property valuation. Consequently, the conceptual model was formulated by integrating insights from various investigated models and aligning with international standards for mineral property valuation.

3.2.1 Crucial Aspects and Boundary of the Conceptual Model

The model integrates the specific assumptions of the modeler to create a comprehensive framework. Initially, a basic causal loop diagram was developed to depict the fundamental structure of investment decision-making within the mining industry. This preliminary model primarily highlights the essential components of investment decision-making and the valuation of mineral properties.

Boundary selection is crucial in developing the System Dynamics (SD) model. Although enhancing the model's resolution through detailed data can be advantageous, it may complicate its validity, especially when incorporating index-based values and qualitative variables. Consequently, the critical process of variable selection is guided by their relevance to the study's objectives and scope. In this research, the variables incorporated into the model are categorized into three groups: endogenous, exogenous, and excluded parameters. This categorization defines the model's boundaries, with the specific variables identified in Table 3-1. Additionally, the model includes converters that implement equations within related subsystems to facilitate simulation.

Project evaluation constitutes a crucial task in investment decision-making within the mining industry, aiming to ascertain the economic feasibility of mining projects. Mining ventures are exposed to both endogenous and exogenous risks. Endogenous risks, such as managerial shortcomings, absenteeism, and workforce irresponsibility, can be managed within a range by mine management. Conversely, exogenous risks, such as economic instabilities of the country, fluctuations in metal prices, and cost variations, are beyond direct control. Despite the uncontrollable nature of exogenous risks, a thorough quantitative assessment of these factors is essential for informed investment decision-making. Accordingly, the previous studies have substantially addressed geological and price uncertainties in the planning and decision-making processes for mining investments.

Table 3-1 The Boundaries Chart for the Investment Decision-Making Model in Mineral Property Investments

Endogenous	Exogenous	Excluded
Production Rate	Mineral Market Demand	Cost Fluctuations
Capability and Experience of Management	Commodity Prices	
Capability and Experience of Technical Team	External Audits	
Corporate Investment Rate	Policy Risk	
Organizational Inertia	Industrial Relations	
Geological Uncertainties	Country Risk	
License		
Mining Rate Capacity		

3.2.2 Stock and Flow Diagram of the Model

A system dynamics model using a stock and flow diagram was developed to simulate the model since it allows for structuring quantitative relationships between the factors. The model comprised parameters under five subsystems: demand, growth strategy, financial, valuation, and production, as shown in Figure 3-1.

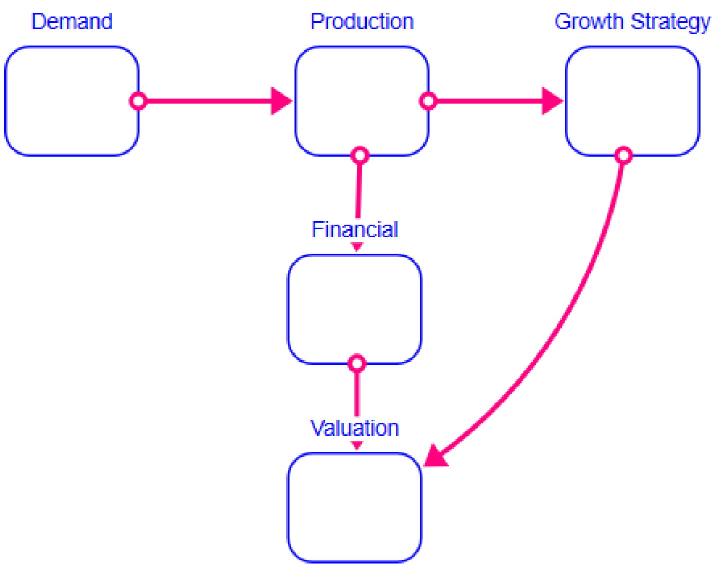

Figure 3-1: The Model Subsystems

The demand module addresses the demand behavior for invested minerals and includes future forecasts. The production module presents the framework driving mineral investment and production. The financial module encompasses critical financial aspects of mineral properties, including financial policies, the financial outputs of the production module, and the financial inputs of the valuation module. The valuation module presents the process of project valuation. The growth strategy module examines how the company's growth strategy impacts its desired size.

The stock-and-flow diagram was constructed using Stella Architect software. The software includes assemblies that provide predefined model structures suitable for various well-known behaviors such as closing gaps, quality allocation, aging chains, and combined effects. Each assembly incorporates specific features and capabilities to explain real-life behaviors. Detailed explanations of each assembly utilized in the model are provided within the relevant subsystem descriptions. The construction of the stock-and-flow diagrams in Stella Architect is guided by the basic building blocks shown in Table 3-2.

Table 3-2 The Building Blocks of a Stock-and-Flow Model (Stella Architect, 2024)

Building Block	Name	Explanation
	Reservoir	The type of stock that passively accumulates its inflows minus any outflows.
	Module	Subsystems that are connectible to other subsystems.
	Converter	The main building blocks that convert inputs into outputs. It can hold constant value, define external inputs, and calculate equations or graphical functions.
	Flow	Flows fill and drain stocks. The flows can be in one direction or bi-directional.
	Connector	The element that connects variables to each other. Connectors indicate an immediate effect.

3.2.3 The Valuation Subsytem

The value of a business is primarily derived from the current valuation of its assets, taking into account its expected future profitability and potential for internal growth minus its liabilities (Barlev and Haddad, 2003). Investors often cannot directly observe managerial actions, resulting in an information asymmetry between shareholders and managers (Kennedy, 1997). This asymmetry can impact both corporate decision-making and the firm's market valuation (Chung et al., 2015). Additionally, the agency problem is a critical factor affecting managerial disclosure practices. According to agency theory (Jensen and Meckling, 1976), managers often prioritize personal short-term gains over the long-term interests of shareholders. Investors interpret managerial decisions as market signals that can deeply influence firm valuation. Thus, incomplete information disclosure becomes critical for achieving a favorable valuation in the market, as it mitigates information asymmetry (McLaughlin and Safieddine, 2008). This situation, in turn, shapes investor behavior differently than if they had access to perfect information (Morellec and Schürhoff, 2011; Shibata and Nishihara, 2011).

Additionally, uncertainty regarding the existence of reserves is a significant industry-specific factor influencing firms' disclosure practices (Ani et al., 2015). Firms disclose financial and non-financial information to mitigate information asymmetry among stakeholders. This study will leverage publicly available data to construct all three modules and estimate the associated parameters. By relying solely on publicly available information, this modeling effort aligns with the information access available to potential investors, ensuring that the analysis is conducted on a level playing field concerning information accessibility. Various methods and approaches are utilized, given the complexities involved in determining the appropriate fair value of mining projects. This study specifically employs Discounted Cash Flow (DCF) methods for the valuation of mining projects. The DCF method is grounded in the principle that a firm's ability to enhance its value depends on its capacity to generate internal growth and cash flows from operations. These cash flows are crucial for financing investment opportunities that propel growth. Furthermore, the firm's ability to secure external financing is influenced by Free Cash Flow (FCF) projections. The dynamic interplay between investment and financial decisions is a key driver of the firm's value.

The valuation module integrates with financial and production modules to create an engine capable of conducting impact analyses on investment policies that influence firm valuation. Within the DCF framework, two critical components—the free cash flow (FCF) estimation and selecting an appropriate discount rate—determine the firm's market value. FCFs represent funds available after fulfilling all obligations and can be reinvested, distributed to shareholders, or retained by the firm. According to Ivanovska et al. (2014), a firm's current value depends on expected future cash flows. The DCF method effectively calculates the present value of expected FCFs, indicating the price an investor is willing to pay for a share based on projected returns. Brealey et al. (2011) underscore the importance of FCFs in investment valuation, mainly as shares are assessed as the present value of an infinite stream of future cash flows. The discount rate in DCF calculations reflects the weighted average cost of capital (WACC), encompassing both debt and equity. FCFs are estimated based on factors from the financial module. In summary, a firm's value is derived from the present value of projected FCFs and terminal value, with each year's discounted FCF contributing to the overall value, while the previous year's value is subtracted to ensure that the valuation reflects the most current information.

The DCF method incorporates essential assumptions and future projections regarding the business, with system dynamics facilitating reality checks and sensitivity analyses to verify the robustness of these projections. Additionally, the DCF approach provides a long-term perspective by leveraging short-term market fluctuations to inform expectations of FCFs over time. This method is particularly effective for valuing individual firms, as it focuses on a comprehensive assessment of the firm itself rather than relying on comparative measures (Koller et al., 2010). An overview of the stock and flow diagram of the valuation subsystem and its parameters is presented in Figure 3-2 and Table 3-3, respectively.

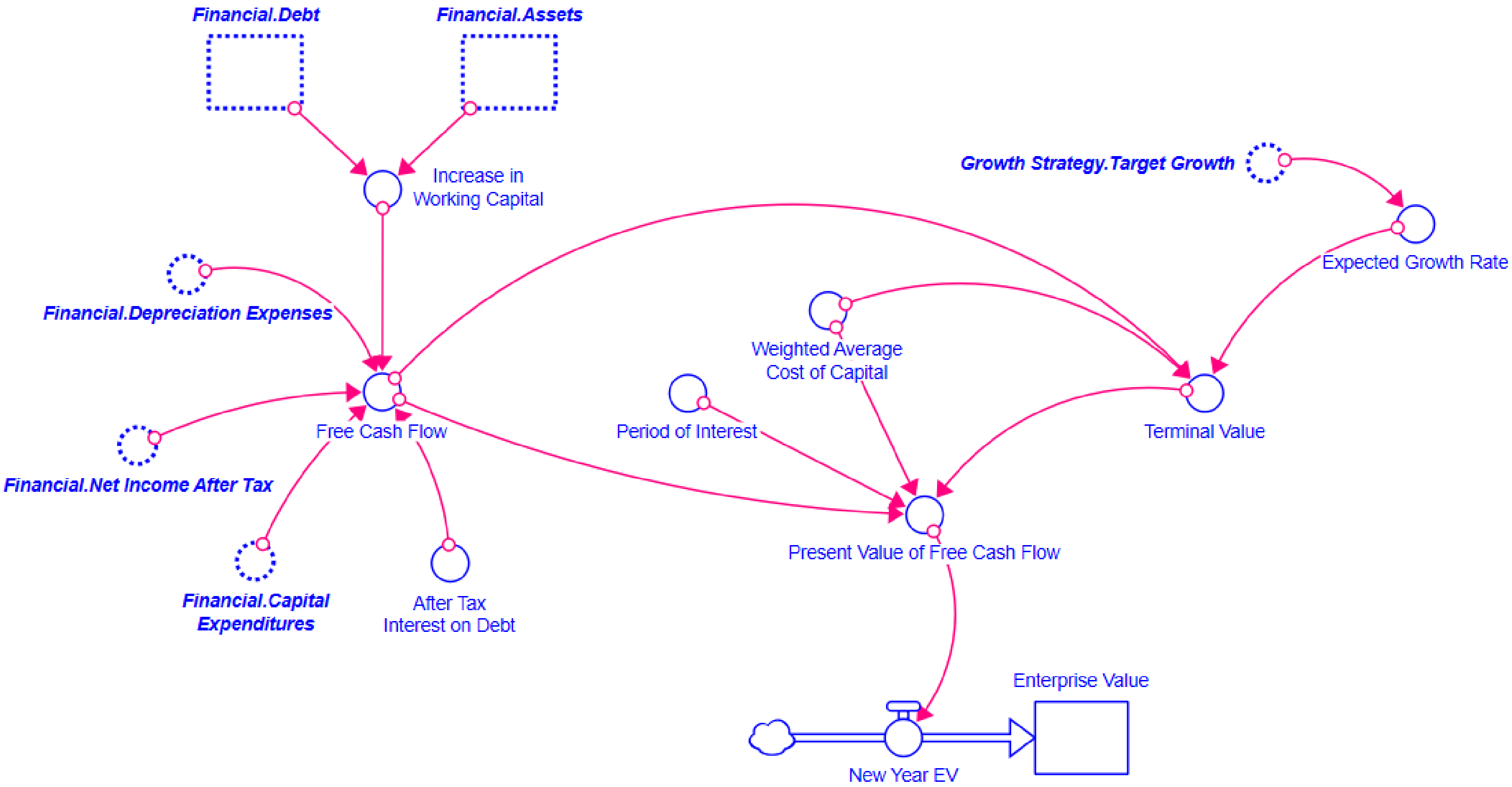

Figure 3-2 Stock and Flow Diagram of the Valuation Subsystem

Table 3-3 Diagram Parameters and Variables of the Valuation Subsystem

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Enterprise Value	Stock	Enterprise Value (EV) is the measure of a company's total value. It looks at the entire market value rather than just the equity value, so all ownership interests and asset claims from both debt and equity are included.	User-defined constant value	$	[0,∞)
New Year EV	Flow	A company's new year enterprise value	Present_Value_of_Free_Cash_Flow	$	(-∞,∞)
Present Value of Free Cash Flow	Converter	The present value of the firm's expected future free cash flow	Free_Cash_Flow/(1+Weighted_Average_Cost_of_Capital)+Terminal_Value/(1+Weighted_Average_Cost_of_Capital)	$	(-∞,∞)
Weighted Average Cost of Capital	Converter	A firm's Weighted Average Cost of Capital (WACC) represents its blended cost of capital across all sources, including common shares, preferred shares, and debt. The cost of each type of capital is weighted by its percentage of total capital and then are all added together.	User-defined constant value	%	[0,∞)
Terminal Value	Converter	Terminal value is the estimated value of a business beyond the explicit forecast period.	(Free_Cash_Flow*(1+Expected_Growth_Rate))/(Weighted_Average_Cost_of_Capital-Expected_Growth_Rate)	$	(-∞,∞)

Table 3-3 Diagram Parameters and Variables of the Valuation Subsystem (cont'd)

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Expected Growth Rate	Converter	The terminal growth rate is the constant rate at which a firm's expected free cash flows are assumed to grow indefinitely. This growth rate is used beyond the forecast period in a discounted cash flow model, from the end of the forecasting period in perpetuity, we will assume that the firm's free cash flow will continue to grow at the terminal growth rate, rather than projecting the free cash flow for every period in the future.	User-defined constant value	%	[0,∞)
Free Cash Flow	Converter	FCF represents the amount of cash generated by a business, after accounting for reinvestment in non-current capital assets by the company.	Financial.Net_Income_After_Tax + Financial.Depreciation_Expenses + After_Tax_Interest_on_Debt-Increase_in_Working_Capital- - Financial.Capital_Expenditures	$	(-∞,∞)
After Tax Interest on Debt	Converter	The interest paid on debt less any income tax savings due to deductible interest expenses.	User	$	(-∞,∞)
Increase in Working Capital	Converter	The Change in Net Working Capital (NWC) section of the cash flow statement tracks the net change in operating assets and operating liabilities across a specified period.	Financial.Debt - Financial.Assets	$	(-∞,∞)

3.2.4 The Production Subsystem

The production module characterizes the physical production of minerals into basic processes: attractiveness to the decision to explore, mineral exploration, mineral resources, mineral reserves, ore production, processed ore and finished product inventory. Attractiveness to the decision to explore defines the effect of jurisdictions and other factors that change the decision to explore. The model uses the Fraser Instıtute Annual Mining Company Survey as a base. However, the questions and factors have been adapted to align with the scope of the thesis. The primary objective of these modifications is to evaluate how exploration decisions influence company production policies, utilizing a globally accepted survey. Table 3-4 outlines the factors identified by Fraser Institute (2023) and a comprehensive literature review.

This study used these factors as determinants of exploration activities. Each factor is ranked before the evaluation, following the ranking methodology outlined in Table 3-5. Changes in mineral exploration motivation reflect the company's interest in exploration sites. This study's total points are derived from the rankings and categorized into the classes shown in Table 3-6. The ranking points are established based on industry experience and consultations with subject matter experts.

Mineral resources are classified as those with a high degree of confidence in their potential to be converted into reserves, specifically categorized as measured and indicated resources. On the other hand, mineral reserves consist of economically viable resources to extract using current technologies and methodologies. Reserve depletion refers to the total quantity of mineral resources extracted over time, including ore stockpiles. Processed ore denotes the cumulative amount processed through mineral processing facilities over a specific period. The production processes involve various delays and nonlinearities, which are modeled to reflect the long-term nature of investments accurately. Production quantity affects production costs, as it determines the operational scale of the firm and influences the remaining mineral reserves. Therefore, production costs are modeled as a nonlinear function of both reserve depletion and mineral reserves.

Table 3-4: The Factors of Attractiveness to Decision to Explore

Factors	Definition
Geological Occurrence of Minerals	A geological occurrence of useful minerals based on initial study.
Effect of Trade Barriers	A trade barrier is any regulation or policy limiting or restricting international trade, including tariffs, quotas, and licensing requirements.
Restrictions of Profit Repatriation	Repatriation of profit refers to a firm's ability to transfer foreign-earned profits or financial assets back to its home country in hard currencies, such as USD or EUR, after fulfilling tax obligations in the host nation. Restrictions on repatriation can negatively impact a company's decision to invest in exploration activities.
Currency Restrictions	Currency controls, also known as foreign exchange controls, refer to restrictions imposed by governments to regulate or limit the sale or purchase of foreign currencies by nationals, as well as the sale or purchase of local currency by foreigners.
Effect of Infrastructure	The infrastructure affects the company's decision about where to explore.
Road Availability	The availability of roads in exploration areas is important for exploration activities.
Power Availability	The power availability of exploration areas is an important factor in exploration activities.
Effect of Environmental Regulations	The mining sector's relationship with the environment involves the environmental consequences of extracting economically significant and widely prevalent minerals. This relationship also includes an overview of how environmental regulations—both specific to the mining sector and more general—impact exploration activities, as well as trends in environmental patent filings related to mining.
Consistency of Regulatory Process	The consistency of the regulatory process affects exploration activities' consistency and the time the exploration project starts.
Timeliness of Regulatory Process	The timeliness of the regulatory process affects the country's selection of exploration activities. The countries' timeliness regulatory process has a positive effect on exploration activities.
Stability of Regulations	The stability of the regulatory process is vital to selecting the location for the exploration activities. The countries that have stable regulations have a positive effect on exploration activities.
Effect of Change in Demand Conditions	The effect of change in demand represents how metal demand affects exploration activities. If demand increases, the exploration activities will be increased as well.
Labor Regulations	Local or national labor regulations influence the wages that companies pay for labor and can also impact issues related to strikes and lockouts.
Availability of Labor & Skills	Mining and exploration activities require skilled personnel for their sustainability. A high availability of labor and skills positively impacts exploration activities.
Effect of Mineral Policy	National mineral policies significantly influence exploration activities. In some countries, a resource-nationalist perspective regarding their deposits adversely affects exploration efforts.
Effect of Land Claims	Territorial disputes often emerge over controlling natural resources, including rivers, arable land, mineral deposits, and petroleum resources. Additionally, these disputes may be influenced by cultural, religious, or ethnic nationalism. Such conflicts can negatively impact exploration activities by generating instability, elevating risk, and potentially leading to legal and operational challenges in the affected regions.
Effect of Company Experience in Country	The company previous experience in the country and its business relationships on the country effects exploration activities positively.

Table 3-5: Ranking and Definitions (Fraser Institute, 2023)

Ranking	Definitions
5	Encourages exploration investment
4	Not a deterrent to exploration investment
3	Is a mild deterrent to exploration investment
2	Is a strong deterrent to exploration investment
1	Would not pursue exploration investment in this region due to this factor

Table 3-6: Ranking Classification

Points	Definitions	Motivation Level
>85	Highly Motivated	Increase Current Exploration Capacities by 75 %
>70	Motivated	Increase Current Exploration Capacities by 50 %
>55	Mildly Motivated	Increase Current Exploration Capacities by 20 %
>45	Less Motivated	Increase Current Exploration Capacities by 10 %
<45	Not Motivated	Protect current exploration activities, not increase new exploration activities.

The firm invests to explore mineral potential beneath the surface, and successful exploration leads to an increase in the stock of mineral resources. After a delay, the time required to develop the reserves becomes the developed reserves, making production possible. The total quantity of minerals is finite. As the mineral deposits are explored, developed, and produced, the quantity in place depletes, making them costlier to extract marginally. A continuous increase in the cumulative mineral production leads to a reduction in the remaining reserves recoverable, resulting in increased marginal extraction costs. This condition requires modeling production costs as a nonlinear function of the cumulative production stock.

Production costs and expected metal prices that determine profit expectation play a significant role in deciding the desired capacity for the future, which determines capital expenditure. A firm must invest at least equal to its depletion and depreciation to maintain its steady state. However, they need to invest more than the steady state investment to increase the capacity. The capacity and reserve development involves major delays that last for many years. The model incorporates the delays through parameters, nonlinear functions, and stock mechanisms to mimic the real system structure. The overall view of the stock and flow diagram of the production subsystem and expressions of the diagram parameters are shown in Figure 3-3 and Table 3-7, respectively.

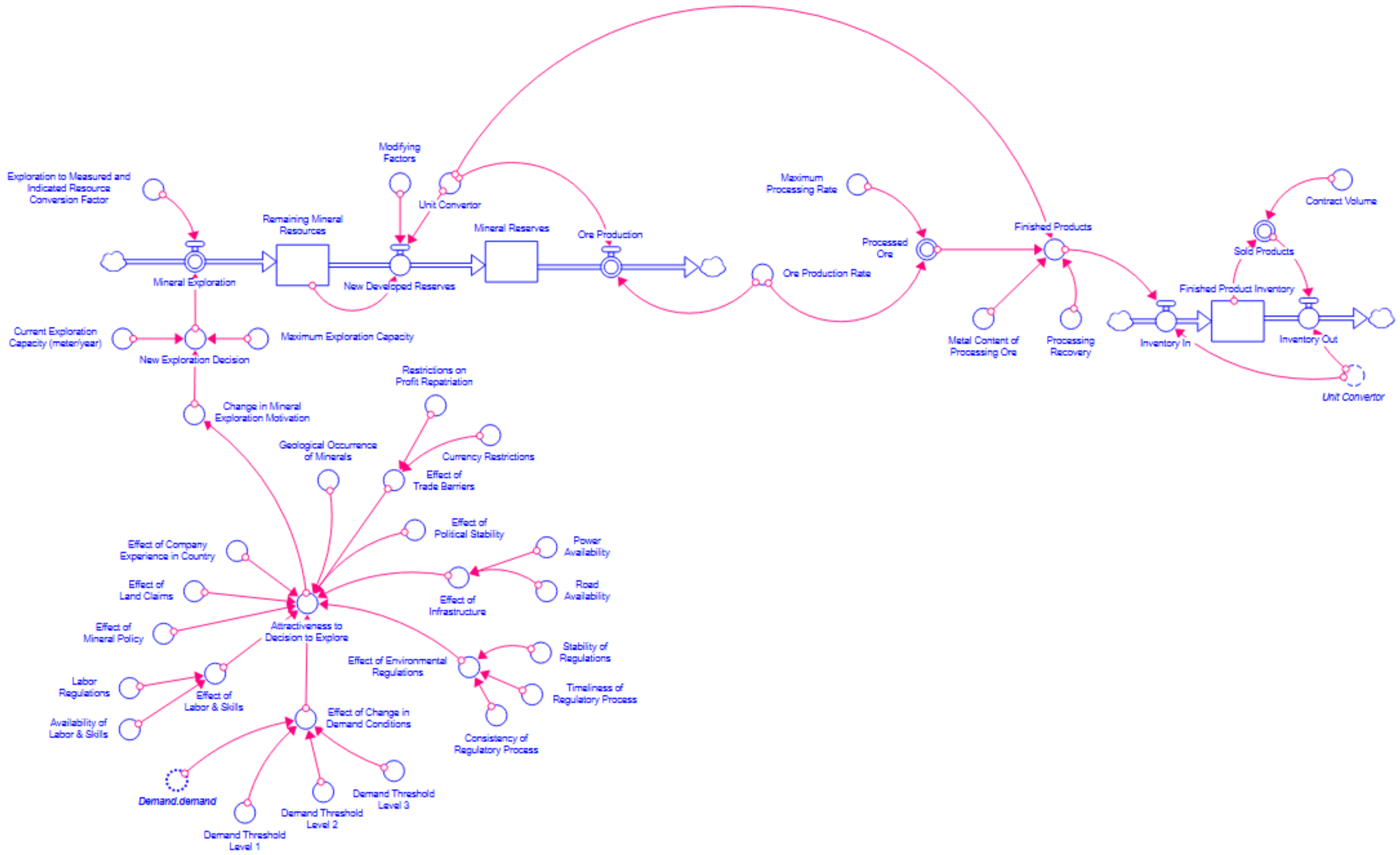

Figure 3-3 Stock and Flow of the Production Subsystem

Table 3-7 Diagram Parameters and Variables of the Production Subsystem

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Processed Ore	Stock	The processed ore measures how many tonnes of ore are processed at a given time.	User-defined constant value	Tonnes	[0,∞)
Maximum Processing Rate	Connector	The maximum capacity of the mineral processing facility	User-defined constant value	Tonnes	[0,∞)
Finished Products	Connector	Finished goods are goods that have completed the manufacturing process but have not yet been sold or distributed to the end user.	Processed_Ore*Processing_Recovery*Metal_Content_of_Processing_Ore	Tonnes	[0,∞)
Metal Content of Processing Ore	Connector	The average metal content of the processing ore	User-defined constant value	Percent	[0,100]
Processing Recovery	Connector	The average recovery of the processed metal from the processing ore	User-defined constant value	Percent	[0,100]
Inventory In	Flow	The annual production of finished goods	Finished_Products	Tonnes	[0,∞)
Finished Product Inventory	Stock	The stock volume of finished goods	User-defined constant value	Tonnes	[0,∞)
Inventory Out	Flow	The amount of material sold	Sold_Products	Tonnes	[0,∞)
Sold Products	Connector	The amount of annual contracted products sold	IF (Finished_Products<1.1*Contract_Volume) THEN (Finished_Products) ELSE (Finished_Products-1.1* Contract_Volume)	Tonnes	[0,∞)
Contract Volume	Connector	The amount of yearly contract volume	TIME	Tonnes	[0,∞)

Table 3-7 Diagram Parameters and Variables of the Production Subsystem (cont'd)

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Mineral Exploration	Flow	Mineral exploration searches for evidence of any mineralization hosted in the surrounding rocks.	New_Production_Capacity * Change_in_Mineral_Exploration	Tonnes	[0,∞)
Exploration to Measured and Indicated Resource Conversion Factor	Connector	The factor of conversion of exploration to measured and indicated part of the resource	User-defined constant value	Percent	[0,100]
Remaining Mineral Resources	Stock	The remaining part of the mineral resources	User-defined constant value	Tonnes	[0,∞)
New Developed Resources	Flow	The newly developed resources indicate that newly developed resources are available via exploration activities.	Remaining_Mineral_Resources*Modifying_Factors	Tonnes	[0,∞)
Modifying Factors	Connector	The term 'Modifying Factor' is common in many industry sectors and is deemed anything that can affect business or product viability. In the minerals sector, this includes "mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social, and governmental" considerations (JORC Code, 2012). This study is based on investigation to understand common ratio between resource to reserve to use as input.	User-defined constant value	Percent	[0,100]

Table 3-7 Diagram Parameters and Variables of the Production Subsystem (cont'd)

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Mineral Reserves	Stock	A mineral reserve is the economically mineable part of a measured and/or indicated mineral resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at pre-feasibility or feasibility level as appropriate, including the application of modifying factors. Such studies demonstrate that extraction could reasonably be justified at the time of reporting. Mineral reserves are subdivided to increase confidence in probable and proven mineral reserves.	Mineral_Resources*Modifying_Factors	Tonnes	[0,∞)
Ore Production	Flow	The cumulative ore production rate from mineral reserves	Ore_Production_Rate	Tonnes	[0,∞)
Ore Production Rate	Connector	The annual ore production rate from mineral reserves	TIME	Tonnes	[0,∞)
Mineral Exploration	Flow	Mineral exploration searches for evidence of any mineralization hosted in the surrounding rocks.	New_Production_Capacity * Change_in_Mineral_Exploration	Tonnes	[0,∞)
Geological Occurrence of Minerals	Converter	A geological occurrence of a mineral refers to any locality where a useful mineral or material is identified based on initial studies.	User-defined constant value	Unitless	[0,5]
Effect of Trade Barriers	Converter	A trade barrier refers to any regulation or policy restricting international trade, especially tariffs, quotas, licenses etc.	Restrictions_on_Profit_Repatriation * Currency_Restrictions	Unitless	[0,5]
Restrictions of Profit Repatriation	Converter	Repatriation of profit is the ability of a firm to send foreign-earned profits or financial assets back to the firm's home country in hard currency, such as USD, EUR and others, after meeting the host nation's tax obligations. Restrictions affect the company decision to explore negatively.	User-defined constant value	Unitless	[0,5]

Table 3-7 Diagram Parameters and Variables of the Production Subsystem (cont'd)

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
Currency Restrictions	Converter	Currency controls, foreign exchange controls or currency exchange controls refer to restrictions applied by some governments to ban or limit the sale or purchase of foreign currencies by nationals and/or the sale or purchase of local currency by foreigners.	User-defined constant value	Unitless	[0,5]
Effect of Infrastructure	Converter	The infrastructure affects the company's decision about where to explore.	Power_Availability * Road_Availability	Unitless	[0,5]
Road Availability	Converter	The availability of roads in exploration areas is important for exploration activities.	User-defined constant value	Unitless	[0,5]
Power Availability	Converter	The power availability of exploration areas is an important factor in exploration activities.	User-defined constant value	Unitless	[0,5]
Effect of Environmental Regulations	Converter	The mining sector's relationship with the environment, environmental consequences of the extraction of the most economically important and prevalent minerals, and an overview of environmental regulation effects on exploration activities, including mining-sector-specific regulations and more general environmental regulations, and mining environmental patterns.	Stability_of_Regulations * Consistency_of_Regulatory_Process * Timeliness_of_Regulatory_Process	Unitless	[0,5]
Consistency of Regulatory Process	Converter	The consistency of the regulatory process affects exploration activities' consistency and the time the exploration project starts.	User-defined constant value	Unitless	[0,5]
Timeliness of Regulatory Process	Converter	The timeliness of the regulatory process affects the country's selection of exploration activities. The countries with timeliness regulatory processes have a positive effect on exploration activities.	User-defined constant value	Unitless	[0,5]
Stability of Regulations	Converter	The stability of the regulatory process affects the selection of countries for exploration activities. Countries that have stable regulations have a positive effect on exploration activities.	User-defined constant value	Unitless	[0,5]
Effect of Change in Demand Conditions	Converter	The effect of change in demand represents how metal demand affects exploration activities. If demand increases, the exploration activities will be increased as well.	IF(Demand_Threshold_Level_1>Demand.Copper_Demand)THEN(0.5) ELSE IF (Demand_Threshold_Level_2>Demand.Copper_Demand) THEN (0.3) ELSE IF (Demand_Threshold_Level_3>Demand.Copper_Demand) THEN (0.1) ELSE (0)	Unitless	[0,5]

Table 3-7 Diagram Parameters and Variables of the Production Subsystem (cont'd)

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Effect of Labor & Skills	Converter	The efficient labor force and its skills are important for the sustainability of exploration and mining activities.	Availability_of_Labor_&_Skills * Labor_Regulations	Unitless	[0,5]
Labor Regulations	Converter	Local or national labor regulations influence the wages companies pay for labor and also affect issues related to strikes and lockouts.	User-defined constant value	Unitless	[0,5]
Availability of Labor & Skills	Converter	The mining and exploration activities require skilled person for their sustainability. The availability of labor and skills has a high positive effect on exploration activities.	User-defined constant value	Unitless	[0,5]
Effect of Mineral Policy	Converter	National mineral policies significantly impact exploration activities. In some countries, a resource-nationalist perspective regarding their deposits adversely affects these exploration efforts.	User-defined constant value	Unitless	[0,5]
Effect of Land Claims	Converter	Territorial disputes are frequently associated with the possession of natural resources, such as rivers, arable land, and mineral or petroleum resources; however, these disputes may also be driven by cultural, religious, and ethnic nationalism. Such conflicts can have a negative impact on exploration activities.	User-defined constant value	Unitless	[0,5]
Effect of Company Experience in Country	Converter	The company's previous experience in the country and business relationships positively affect exploration activities.	User-defined constant value	Unitless	[0,5]
Attractiveness to Decision to Explore	Converter	The attractiveness of the decision to explore reflects a company's interest in exploration sites, which serves as a critical decision point for investment. Based on the Fraser Institute's Annual Mining Survey, a multiplier of 0.4 is applied to parameters other than geological occurrences. For geological occurrences of minerals, a multiplier of 0.6 is utilized to assess the attractiveness of decision-making factors related to exploration.	0.4*(Effect_of_Company_Experience_in_Country + Effect_of_Land_Claims + Effect_of_Mineral_Policy + Effect_of_Labor_&_Skills + Effect_of_Change_in_Demand_Conditions + Effect_of_Environmental_Regulations + Effect_of_Infrastructure + Effect_of_Political_Stability + Effect_of_Trade_Barriers)+0.6*Geological_Occurrence_of_Minerals	Percent	[0,100]
Change in Mineral Exploration Potential	Converter	The change in mineral exploration potential reflects a company's potential for engaging in mineral exploration activities.	Attractiveness_to_Decision_to_Explore/100	Percent	[0,100]

Table 3-7 Diagram Parameters and Variables of the Production Subsystem (cont'd)

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
New Exploration Decision	Converter	The company's decision about the new exploration	MIN((IF(Change_in_Mineral_Exploration_Motivation<0.45)THEN("Current_Exploration_Capacity_(meter/year)")ELSE IF (Change_in_Mineral_Exploration_Motivation<0.55) THEN ("Current_Exploration_Capacity_(meter/year)"*1.1) ELSE IF (Change_in_Mineral_Exploration_Motivation<0.70) THEN ("Current_Exploration_Capacity_(meter/year)"*1.2) ELSE IF(Change_in_Mineral_Exploration_Motivation< 0.85) THEN ("Current_Exploration_Capacity_(meter/year)"*1.5) ELSE ("Current_Exploration_Capacity_(meter/year)"*1.75)), Maximum_Exploration_Capacity)	Meters/year	[0,∞)
Maximum Exploraiton Capacity	Converter	It describes the company's maximum exploration capacity	User-defined constant value	Meters/year	[0,∞)
Current Exploration Capacity	Connector	It describes the company's current exploration capacity	User-defined constant value	Meters/year	[0,∞)

3.2.5 The Growth Strategy Subsystem

The company's growth strategy is grounded in its chosen approach to expansion, which can take three distinct forms: organic growth, inorganic growth, and strategic partnerships. Organic growth refers to the increase in output and sales achieved internally, without accounting for profits or growth resulting from mergers and acquisitions; it relies solely on the company's own resources. Organic growth can be synonymous with mineral exploration within the company's existing assets in the mining industry. In contrast, inorganic growth refers to expanding business operations and sales through mergers, acquisitions, and takeovers. Strategic partnerships involve formal agreements between two or more parties—either bilateral or network partnerships—aimed at sharing financial resources, skills, information, and other assets to achieve common objectives.

In this thesis, these three types of growth form the foundation of the company's growth strategy, as the organization may choose to employ one, two, or all three in its strategic planning. Company policies play a crucial role in shaping this growth strategy. These policies serve as guidelines for managing employee health, safety, accountability, and interactions with customers or clients. Furthermore, company policies can influence asset acquisition in legal and accounting contexts. Ultimately, asset acquisition and the growth strategy determine the company's enterprise value growth, representing the anticipated expansion rate following the initial projected growth period. The current enterprise value (EV) reflects the total value of the company in its present state, while the desired enterprise value (EV) denotes the total value the company aims to achieve in the future.

The overall view of the stock and flow diagram of the growth strategy subsystem and expressions of the diagram parameters are shown in Figure 3-4 and Table 3-8, respectively.

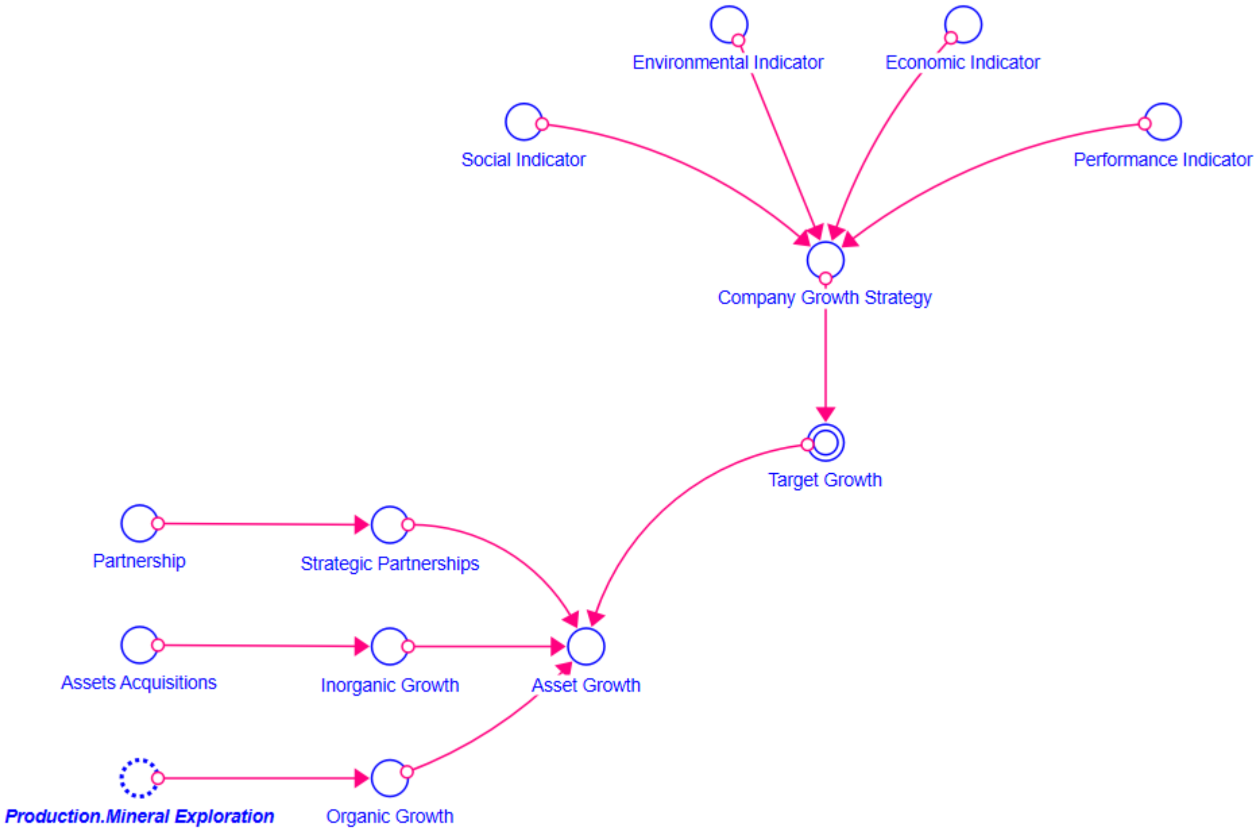

Figure 3-4 Stock and Flow Diagram of the Growth Strategy Subsytem

Table 3-8 Diagram Parameters and Variables of the Growth Strategy Subsystem

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Asset Growth	Connector	The asset growth indicates that company growth in terms of asset.	MIN(Organic_Growth*Inorganic_Growth*Strategic_Partnerships, Target_Growth)	%	[0,100]
Organic growth	Connector	Organic growth is the growth a company achieves by increasing output and enhancing sales internally. This does not include profits or growth attributable to mergers and acquisitions but rather an increase in sales and expansion through the company's own resources.	Production.Mineral_Exploration	$	[0,∞)
Strategic Partnerships	Connector	A strategic partnership involves some shape of formal agreement between two (a bilateral partnership) or more (a network partnership) parties that have agreed to share finance, skills, information and/or other resources in the pursuit of common goals.	User-defined constant value	$	[0,∞)
Target Growth	Connector	Target growth is the rate a company aims to achieve in its overall growth objectives.	Company_Growth_Strategy*TIME	%	[0,100]

Table 3-8 Diagram Parameters and Variables of the Growth Strategy Subsystem (cont'd)

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Company Growth Strategy	Connector	A growth strategy is a plan companies make to expand their business in a specific aspect, such as yearly revenue, number of customers, or number of products. Specific growth strategies can include adding new locations, investing in customer acquisition, or expanding a product line.	Company_Policies * Inorganic_Growth * Strategic_Partnerships * Organic_Growth	Dimensionless	
Social Indicator	Connector	The social indicators include population, equity, employment and training, social-cultural services, education etc. Key issues emerge when mining companies invest in rural areas.	User-defined constant value	unitless	[0,5]
Environmental Indicator	Connector	The environmental indicators examine environmental issues such as pollution, biodiversity, climate, energy, erosion, ecosystem, etc, regarding company growth.	User-defined constant value	unitless	[0,5]
Economic Indicator	Connector	The economic indicator examines company revenue growth, cost efficiency, enterprise value growth etc, in terms of company growth.	User-defined constant value	unitless	[0,5]
Performance Indicator	Connector	The performance indicator examines company production performance etc, in terms of company growth.	User-defined constant value	unitless	[0,5]
Asset Acquisitions	Connector	An asset acquisition is the purchase of a company by buying its assets instead of its stock.	Financial.Investments * Company_Policies * Demand.Copper_Demand	$	[0,∞)

3.2.6 The Demand Subsystem

Mineral resource consumption is influenced by factors such as gross domestic product (GDP), total consumption, and population. The interactions among these variables can be represented through a set of differential equations. Figure 3-4 presents a representative system dynamics model in which two cumulative variables—copper demand and GDP—are treated as stocks. The annual changes in these stocks are defined by corresponding flow rates, reflecting the yearly increments in demand and GDP within the model. In this system dynamics (SD) model, the GDP increment is calculated as the product of the current GDP stock and the growth rate. Both copper demand and GDP are simulated values that may differ from their counterparts for a given year. To address this mismatch, this study introduces two functions: Error in Copper Demand and Error in GDP, which quantify the annual differences between the simulated and actual values of copper demand and GDP, respectively.

The overall view of the stock and flow diagram for the demand subsystem, along with the expressions of the diagram parameters, is shown in Figure 3-5 and detailed in Table 3-9.

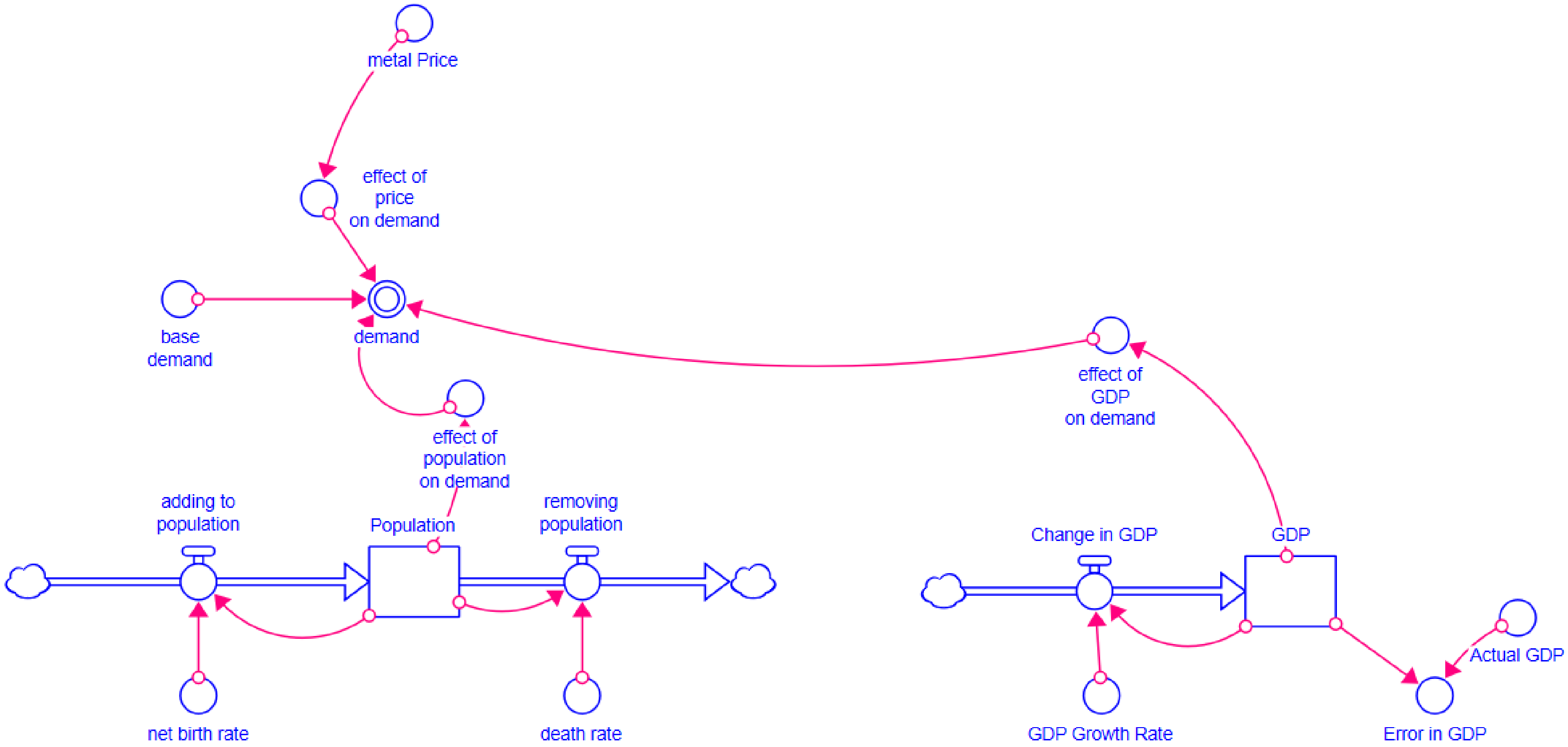

Figure 3-5 Stock and Flow Diagram of the Demand Subsytem

Table 3-9 Diagram Parameters and Variables of the Demand Subsystem

Name	Type	Variable Explanation	Equation	Unit	Range of Values
Population (t)	Stock	Global population	User-defined constant value	Unitless	[0,∞)
GDP (t)	Stock	Global GDP	User-defined constant value	Unitless	[0,∞)
Adding to population	Flow	The rate of adding to the population	Population * net_birth_rate	Unitless	[0,∞)
Change in GDP	Flow	The rate of change in GDP	GDP*GDP_Growth_Rate/100	Percent	[0,100]
Removing population	Connector	The rate of removing population	Population * death_rate	Unitless	[0,∞)
Error in GDP	Connector	The difference between actual GDP and forecast	(GDP-Actual_GDP)/GDP	Percent	[0,100]
Actual GDP	Connector	Manually entering calendar year number	User-defined constant value	$	[0,∞)
Net birth rate	Connector	The average birth rate in the world annually	User-defined constant value	Percent	[0,100]
Death rate	Connector	The average death rate in the world annually	User-defined constant value	Percent	[0,100]
Effect of population on demand	Connector	The effect of population on demand	Population/1000	Percent	[0,100]
Demand	Connector	The annual demand for specified mineral	base_demand * (effect_of_price_on_demand *0.25+ effect_of_GDP_on_demand *0.35+ effect_of_population_on_demand*0.4)	Unitless	[0,∞)
Base demand	Connector	Manually entering calendar year number	User-defined constant value	Percent	[0,100]
Effect of price on demand	Connector	The effect of price on demand	IF(metal_Price>8000)THEN(0.1) ELSE IF (metal_Price>9000) THEN (0.15) ELSE IF (metal_Price>10000) THEN (0.3) ELSE IF (metal_Price>12500) THEN (0.5) ELSE IF (metal_Price>15000) THEN (0.75) ELSE (0)	Percent	[0,100]
Effect of GDP on demand	Connector	The effect of GDP on demand	GDP/1000000	Unitless	[0,∞)
Metal price	Connector	Manually entering current market value	User-defined constant value	Percent	[0,100]

3.2.7 The Financial Subsystem

Production, an input from the production module, generates the sales subject to the prevailing commodity price in the market. The calculation of sales minus all relevant expenses gives net income before taxes. After paying taxes and dividends, the remaining amount flows into the retained earnings. Capital expenditure depends on the desired capital budget subject to the financing available. The desired capital budget is determined by the desired capacity based on future expectations for mineral prices and production costs. The desired capacity is an input from the production module.

Moreover, the desired capital budget reflects the firm's intended investments aimed at building future capacity, with internal sources prioritized as the primary financing option. If additional capital is necessary to achieve the investment objectives, external financing—such as external debt and equity—becomes the subsequent alternative. Consequently, the actual capital expenditure allocated to investments in new assets is financed through internal cash flow, new debt, and new equity. The firm leverages these assets to produce metals in alignment with its corporate strategies and investment policies developed to address future demands.

The overall view of the stock and flow diagram of the financial subsystem and expressions of the diagram parameters are shown in Figure 3-6 and Table 3-10, respectively.

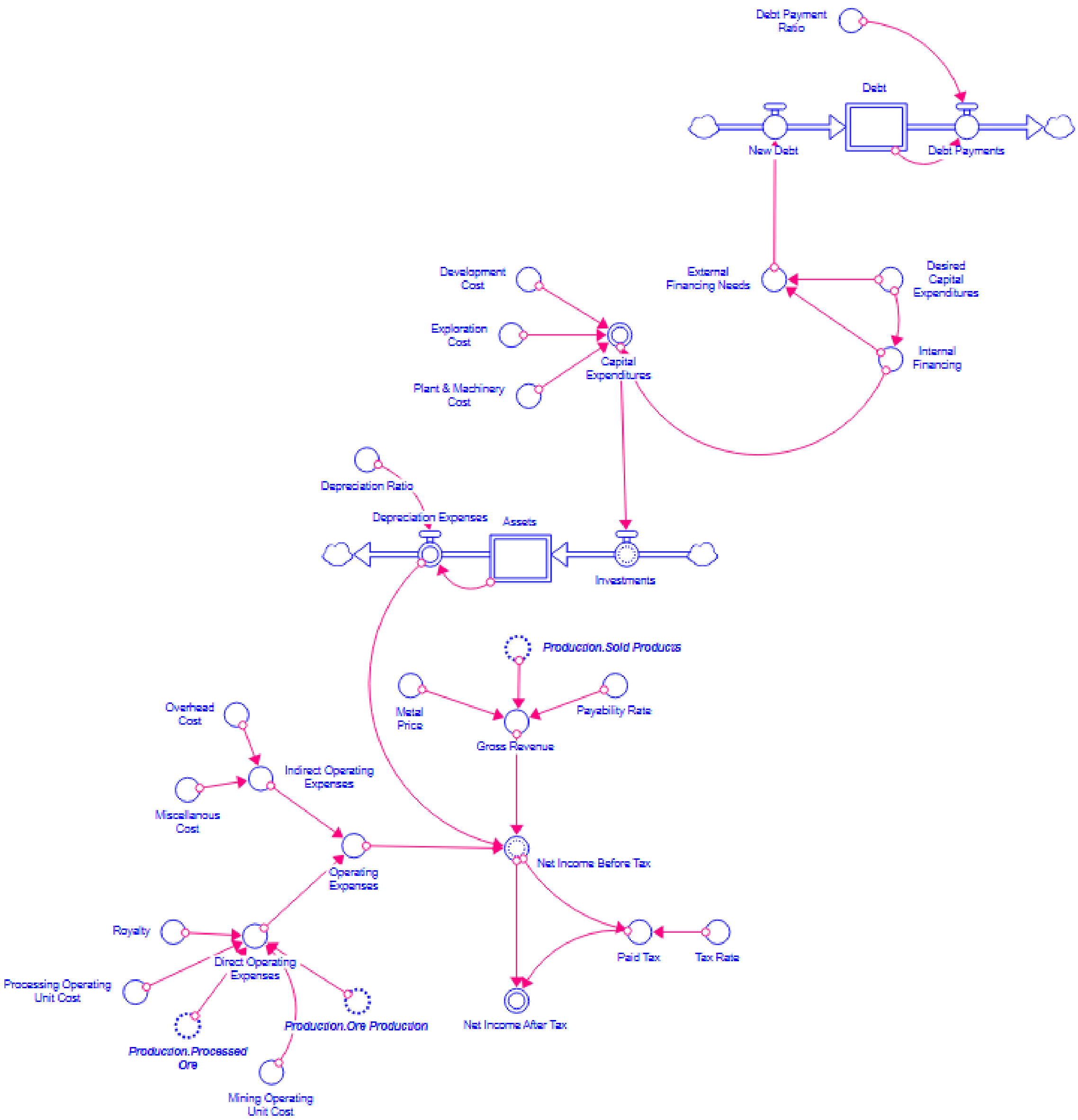

Figure 3-6 Stock and Flow Diagram of the Financial Subsytem

Table 3-10 Diagram Parameters and Variables of the Financial Subsystem

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
Assets	Stock	An asset is a resource owned or controlled by an individual, corporation, or government with the expectation of generating positive economic benefits. In this context, assets may include exploration sites, development sites, or producing assets.	User-defined constant value	Dimensionless	[0,∞)
Debt	Stock	Debt is the money borrowed by one party from another to serve a financial need that otherwise cannot be met outright.	User-defined constant value	Dimensionless	[0,∞)
New Debt	Flow	This term refers to new debt incurred by mining companies to finance investment activities related to acquiring mineral properties.	External_Financing_Needs	$	[0,∞)
Debt Payments	Flow	Debt payments refer to the total amount of a company's liabilities for a specified period.	Debt	$/year	[0,∞)
Debt Payment Ratio	Converter	The debt payment ratio is the proportion of a company's liabilities allocated to the relevant percentage of its debt obligations.	User-defined constant value	Percent	[0,100]
Investments	Flow	Investment is the process of allocating capital to mineral properties based on the expectation of realizing specific benefits in the future.	Capital_Expenditures	$	[0,∞)
Depreciation Expenses	Flow	Depreciation expense refers to the portion of a company's assets allocated as depreciation for a specific period, whereas accumulated depreciation represents the cumulative total of depreciation recognized to date.	Assets	$	[0,∞)
Desired Capital Expenditures	Converter	Estimated capital expenditures from a company to develop new mineral assets	Production.New_Production_Capacity	$	[0,∞)

Table 3-10 Diagram Parameters and Variables of the Financial Subsystem (cont'd)

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
External Financing Needs	Converter	A required amount of capital to develop or buy mineral assets that buyers need to use from external sources such as banks, etc.	Desired_Capital_Expenditures-Internal_Financing	$	[0,∞)
Internal Financing	Converter	A required amount of capital to develop or buy mineral assets that buyers use from internal sources such as cash on banks etc.	User-defined constant value	$	[0,∞)
New Equity	Converter	New equity is the value attributable to the mineral properties.	External_Financing_Needs	$	[0,∞)
Capital Expenditures	Connector	A capital expenditure ("CapEx" for short) is the payment with either cash or credit to purchase long-term physical or fixed assets used in a business's operations.	New_Equity + Internal_Financing + Development_Cost + Exploration_Cost + Plant_&_Machinery_Cost + New_Debt	$	[0,∞)
Plant and Machinery Cost	Connector	A plant and machinery cost is the payment with either cash or credit to purchase plant and machinery used in a business's operations.	User-defined constant value	$	[0,∞)
Development Cost	Connector	A development cost is a payment with either cash or credit to develop mineral properties used in a business's operations.	User-defined constant value	$	[0,∞)
Exploration Cost	Connector	An exploration cost is a payment with either cash or credit to explore mineral properties to develop mineral properties.	User-defined constant value	$	[0,∞)

Table 3-10 Diagram Parameters and Variables of the Financial Subsystem (cont'd)

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
Processing Rate	Connector	An annual rate of ore processed through mineral processing facilities	User-defined constant value	tonnes/year	[0,∞)
Processing Recovery	Connector	A recovery of minerals in mineral processing facilities	User-defined constant value	%	[0,100]
Metal Price	Connector	A price of related commodities on the exchange market	User-defined constant value	$/tonnes	[0,∞)
Payability Rate	Connector	A rate of payability of metal on the final product such as concentrate or copper cathode	formula	%	[0,100]
Gross Revenue	Connector	All income from relevant sales	Production.Processing_Rate*Processing_Recovery*Payability_Rate*Metal_Price	$	(-∞,∞)
Net Income Before Tax	Connector	Net Income Before Tax is the residual income of a business after accounting for all expenses but before deducting tax liabilities.	Gross_Revenue-(Depreciation_Expenses+Operating_Expenses)		
Mining Operating Cost	Connector	Unit cost of producing one tonne of ore	User-defined constant value	$/tonnes	[0,∞)
Processing Operating Cost	Connector	Unit cost of processing one tonne of ore	User-defined constant value	$/tonnes	[0,∞)
Royalty	Connector	Mining royalties are agreements that provide a mining company with a one-time payment in exchange for a share of future revenues.	User-defined constant value	$	[0,∞)

Table 3-10 Diagram Parameters and Variables of the Financial Subsystem (cont'd)

Name	**Type**	**Variable Explanation**	**Equation**	**Unit**	**Range of Values**
Production.Processing Rate	Connector	An annual rate of ore processed through mineral processing facilities	User-defined constant value	tonnes/year	[0,∞)
Production.Mine Production Rate	Connector	An annual rate of ore produced from mining operations	User-defined constant value	tonnes/year	[0,∞)
Direct Operating Cost	Connector	Direct Operating Costs include all applicable expenditures required to operate and maintain a building over its entire life.	Royalty + (Processing_Operating_Unit_Cost*Production.Processing_Rate) + (Mining_Operating_Unit_Cost* Production.Mine_Production_Rate)	$	[0,∞)
Overhead Cost	Connector	Overhead costs are not directly related to the production of goods or services but are necessary for the operation of a business.	User-defined constant value	$	[0,∞)
Miscellaneous Cost	Connector	Miscellaneous expenses can be defined as costs that generally do not fit any specific account ledger or tax category.	User-defined constant value	$	[0,∞)
Indirect Cost	Connector	An indirect cost is money a business spends even when it's not selling goods or delivering services.	Miscellanous_Cost + Overhead_Cost	$	[0,∞)
Total Operating Cost	Connector	The total cost of producing and processing ore to produce a sellable product	Indirect_Operating_Cost + Direct_Operating_Cost	$	[0,∞)
Tax Rate	Connector	A tax rate is a percentage at which an individual or corporation is taxed.	User-defined constant value	%	[0,100]
Paid Tax	Connector	An amount paid to the government based on a company's profits	Gross_Profit * Tax_Rate	$	[0,∞)
Net Profit After Tax	Connector	the money a company has left over after it accounts for all costs and expenses, including tax.	Net_Income_Before_Tax-Paid_Tax	$	(-∞,∞)

CHAPTER 4

IMPLEMENTATION OF THE DEVELOPED MODEL FOR A COPPER MINE INVESTMENT

4.1 Introduction

This section outlines the implementation of the developed system dynamics model utilizing a hypothetical input dataset designed to represent the conditions of a typical mining company in Türkiye seeking to invest in a copper mine within an emerging market. The dataset was created through research based on the annual reports of mining companies, with certain aspects informed by expert opinions. It is essential to note that the model's outcomes are sensitive to parameter values and initial variable conditions, which may lead to diverse results among different companies. A comprehensive discussion of the input dataset and optimization results will be presented in Section 4.2.

4.2 Case Study

The proposed system dynamics model was applied to a hypothetical open-pit copper mine with an annual capacity of 0.85 million tonnes of run-of-mine copper ore. The dataset, which includes financial and operational data, was developed based on research focused on companies of similar size. The inputs derived from this dataset, acquired by brief consultations with experts and relevant annual reports, are detailed in Section 4.2.1. The results of the implementation are subsequently discussed in Section 4.2.2.

4.2.1 Input Dataset of the Algorithm

To test the model, it was computed for a typical open-pit copper mine in Türkiye using Stella Architect v.3.7.1. A hypothetical mine with an annual production capacity of 0.85 million tonnes of run-of-mine copper ore was selected for this study. The chosen mine initially undertook 50,000 meters per year of exploration activities, with a maximum capacity of 75,000 meters per year. The average metal content of the mine is 1% copper, and the average processing recovery rate is set at 85%. The company begins with assets and enterprise value of 10,000,000 MUSD, aiming to increase its enterprise value to 15,000,000 MUSD.

Copper prices are expressed in USD, and the demand for copper is initially based on the current year's calendar value. Specifically, the production cost of the mine is $2 per tonne of copper ore, while the processing cost is $20 per tonne of ore processed. Table 4.1 presents the model inputs for this hypothetical open-pit copper mine in Turkey, which is a typical example of an emerging market.

Table 4-1: Input Dataset to Hypothetical Study

Subsystem	**Name**	**Type**	**Value**	**Unit**
Demand	Population (t)	Stock	8,200,000,000	Unitless
	GDP (t)	Stock	100,562,000,000,000	Unitless
	Actual GDP	Connector	110,000,000,000,000	$
	Net birth rate	Connector	1,730	Percent
	Death rate	Connector	775	Percent
	Base demand	Connector	28,000,000	tonnes
	Metal price	Connector	8,500	$/tonnes
Valuation	Enterprise Value	Stock	10,000,000	$
	Weighted Average Cost of Capital	Converter	14	%
	Expected Growth Rate	Converter	8	%
Production	Processed Ore	Stock	850,000.00	Tonnes
	Maximum Processing Rate	Connector	870,000.00	Tonnes
	Metal Content of Processing Ore	Connector	1.00	Percent
	Processing Recovery	Connector	85.00	Percent
	Finished Product Inventory	Stock	200.00	Tonnes
	Exploration to Measured and Indicated Resource Conversion Factor	Connector	15.00	Percent

Table 4-1: Input Dataset to Hypothetical Study (cont'd)

Subsystem	Name	Type	Value	Unit
Production (cont'd)	Remaining Mineral Resources	Stock	5,000,000.00	Tonnes
	Modifying Factors	Connector	25.00	Percent
	Geological Occurrence of Minerals	Converter	4.00	Unitless
	Restrictions of Profit Repatrition	Converter	4.00	
	Currency Restrictions	Converter	3.00	Unitless
	Road Availability	Converter	2.00	Unitless
	Power Availability	Converter	2.00	Unitless
	Consistency of Regulatory Process	Converter	4.00	Unitless
	Timeliness of Regulatory Process	Converter	4.00	Unitless
	Stability of Regulations	Converter	4.00	Unitless
	Labor Regulations	Converter	3.00	Unitless
	Availability of Labor & Skills	Converter	4.00	Unitless
	Effect of Mineral Policy	Converter	4.00	Unitless
	Effect of Company Experience in Country	Converter	3.50	Unitless
	Maximum Exploration Capacity	Converter	50,000.00	Meters/year
	Current Exploration Capacity	Connector	75,000.00	Meters/year
Growth Strategy	Current Enterprise Value	Stock	10,000,000.00	$
	Desired Enterprise Value	Stock	15,000,000.00	$
	Strategic Partnerships	Connector	4.00	$
	Social Indicator	Connector	4.00	unitless
	Environmetal Indicator	Connector	3.50	unitless
	Economic Indicator	Connector	4.00	unitless
	Performance Indicator	Connector	4.00	unitless
Financial	Assets	Stock	100,000,000.00	Dimensionless
	Debt	Stock	25,000,000.00	Dimensionless
	Debt Payment Ratio	Converter	20.00	Percent
	Processing Rate	Connector	850,000.00	tonnes/year
	Processing Recovery	Connector	85.00	%
	Metal Price	Connector	8,500.00	$/tonnes
	Mining Operating Cost	Connector	2.00	$/tonnes
	Processing Operating Cost	Connector	20.00	$/tonnes
	Royalty	Connector	3,500,000.00	$
	Production.Processing Rate	Connector	850,000.00	tonnes/year
	Production.Mine Production Rate	Connector	1,000,000.00	tonnes/year
	Overhead Cost	Connector	3.50	$
	Miscellanous Cost	Connector	1.50	$
	Tax Rate	Connector	25.00	%

In the demand submodules, copper demand figures for 2024 are utilized, alongside approximate current values for population, GDP, birth rate, and death rate, which have been rounded or adjusted for the purposes of this study. In the valuation submodules, the enterprise value is assumed to reflect the average size of mining companies in the country, while the weighted average cost of capital and expected growth rate are indicative of prevailing market conditions. For the production submodules, processing capacity, recovery rates, and metal content of ore are derived from averages of similarly sized copper projects worldwide. Factors influencing the attractiveness of exploration decisions, such as geological occurrences and labor regulations, were discussed with subject matter experts. In the growth strategy submodules, both the current and desired enterprise values are assumed to represent the average size of mining companies in the country, with additional data gathered through expert consultations. Lastly, the financial submodules are based on averages corresponding to the size of mining companies in the country and existing market conditions.

4.2.2 Results and Discussion of the Optimization Outputs

After establishing the input dataset, the developed system dynamics model was utilized to explore investment decision-making and its parameters across multiple submodules, each reflecting different characteristics of the mining industry. Given the inherent uncertainties associated with the mining sector and the initial life of the hypothetical mine, the model was executed over five years. This duration corresponds to the mine's projected lifespan. Time units were defined as years, with fractional runs employed to represent each quarter-end, consistent with contemporary financial reporting practices; thus, the simulation produced results throughout five years. The results were evaluated in five main aspects: Demand, New Exploration Decisions, Mineral Reserves, Target Growth, and Enterprise Value.

Demand

The primary outcome of the model is the demand for relevant minerals, which is crucial for guiding investment decisions within the mining sector. The model was constructed to estimate mineral demand based on several key variables, including GDP, metal prices, population dynamics, and baseline demand. The demand for a particular mineral or metal significantly influences investment strategies, especially in the context of current trends, such as the increasing demand for copper driven by electrification initiatives. As demand for copper rises, mining and exploration companies actively seek undeveloped copper resources to meet this emerging need. This heightened demand affects the price of copper and indirectly impacts the financial performance of companies over time, as shifts in demand characteristics can lead to fluctuations in revenue and investment viability. For instance, a sustained increase in copper demand can lead to higher prices, enhancing profit margins for producers and influencing their capital allocation decisions.

The model's simulation results indicate that the projected demand at the end of the five years is 29.8 million tonnes. This demand figure is consistent with global forecasts and falls within acceptable limits, suggesting that the model effectively captures the market dynamics. Such insights are vital for stakeholders in the mining industry, enabling them to make informed decisions regarding exploration, resource allocation, and investment in infrastructure to capitalize on emerging opportunities in the mineral sector.

New Exploration Decision

Based on the model outcomes from the production modules, a critical aspect of the analysis is the decision-making process regarding new exploration activities. The results indicate that changes in mineral exploration motivation yield an outcome value of 0.42. This value suggests that the company is expected to maintain its current exploration capacity of 50,000 meters per year, as outlined in the ranking classification discussed in the previous section (Table 3-5).

This decision to preserve exploration capacity is significant in the context of resource management and strategic planning within the mining sector. An outcome value of

0.42 indicates that by prioritizing the protection of existing exploration capacity, the company can effectively manage its operational risks while remaining adaptable to potential future opportunities.

Mineral Reserves

Mineral reserves are essential for the mining industry's sustainability, as they indicate the quantity of resources available for extraction. Increases in mineral reserves can result from various factors, including new discoveries, advancements in extraction technologies, and enhanced exploration techniques. Based on its new exploration strategy, the company has determined that it aims to conduct 50,000 meters of exploration annually. This decision will impact the company's mineral reserves over time.

Given the current study, the company operates production facilities, suggesting that mineral reserves will naturally decrease due to depletion. However, the company's decision to invest in exploration at this site is projected to increase its mineral reserves to 5.95 million tonnes over five years. This mineral reserve figures represent the sum of reserve to be mined, and new developed reserves within 5 year time span current exploration activities. Additionally, advancements in mining methods can make previously uneconomical reserves viable, thereby enhancing the total reserves available for production. This increase is crucial for sustaining the industry's future and meeting the growing global mineral demand.

Achieving mineral reserves of 5.95 million tonnes after five years underscores both the potential for continued production and the necessity for strategic planning. Understanding these reserves enables companies to effectively balance economic viability with environmental responsibility, ensuring long-term operational success. The results of this analysis are presented in Figure 4.1, highlighting the significance of informed decision-making in mineral resource management.

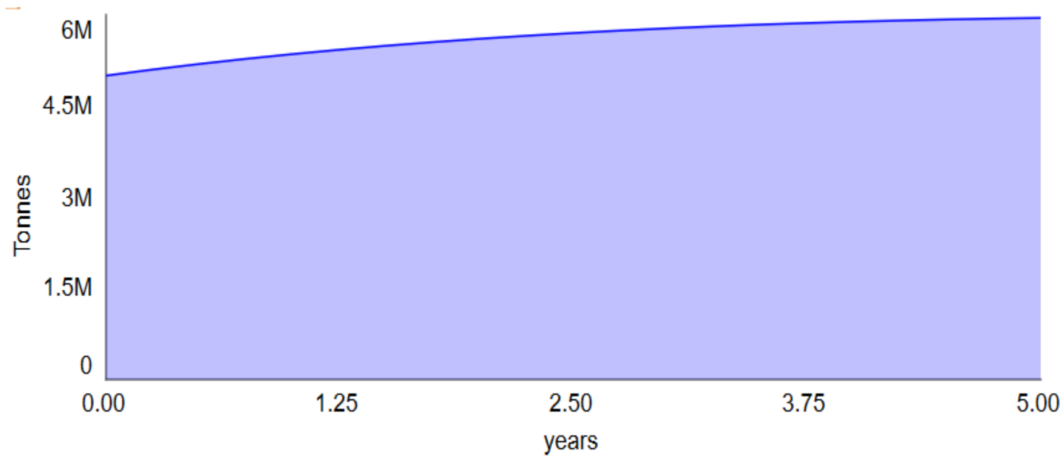

Figure 4-1 Variation the Mineral Reserves in Time

Target Growth

Target growth in terminal value refers to the anticipated long-term growth rate of a company's cash flows beyond the explicit forecast period in a discounted cash flow (DCF) analysis. This growth rate is crucial for estimating terminal value, representing the company's worth at the end of the projection period. Typically, the target growth rate should be realistic, often aligned with long-term economic growth or industry trends, and can be calculated using the Gordon Growth Model. A higher target growth rate can significantly boost the terminal value, influencing the overall company valuation and attracting investors. However, assessing the risks associated with this growth rate is essential, as overly optimistic projections may lead to inflated valuations. Conducting sensitivity analyses on the target growth rate helps investors understand how variations affect terminal value, providing deeper insights into potential valuation scenarios. The target growth is the main output of the growth strategy modules. It affects both companies' decisions about how to continue the growth. As an input of the expected growth rate, the valuation modules directly affect the project's terminal value. The terminal value was found to be 11.2 % based on the given input. It increases the terminal value, increasing investors' attractiveness to the project and company terminal value.

Enterprise Value

Enterprise value is a crucial metric for assessing a company's overall worth, particularly in the context of investment and acquisition decisions. It offers a comprehensive financial health view by incorporating debt and cash levels, enabling stakeholders to make informed decisions based on the company's true market value. The following key factors influence enterprise value:

- Debt Levels: An increase in debt, such as through new loans or bond issuances, raises enterprise value, while debt reduction decreases it.
- Cash Reserves: Increased cash reserves lower enterprise value, as higher liquidity provides potential buyers with more resources to acquire or invest.
- Operational Performance: Factors such as revenue growth, profit margins, and overall financial health significantly influence investor perception and stock prices, thereby impacting enterprise value.
- Market Conditions: Broader economic trends, including interest rates and market volatility, can affect stock prices, influencing enterprise value.
- Industry Dynamics: Changes in industry regulations, competitive landscapes, or technological advancements can alter market perception and operational performance, leading to fluctuations in enterprise value.

In this model, enterprise value is a primary output that directly impacts investment decisions related to mining projects. If enterprise value is projected to grow over the specified period, as indicated by the project inputs, the company will likely pursue related investments. Conversely, the company may stop investing in those projects if enterprise value does not show anticipated growth. The variations in the EV are illustrated in Figure 4.2, providing a visual representation of these dynamics. The initial enterprise value of 10,000,000 USD with increase 78.9 million USD and based on input data company desired enterprise value is 15 million USD. This represents that achievable enterprise value for that project higher than company expectations. So, company can invest for that project.

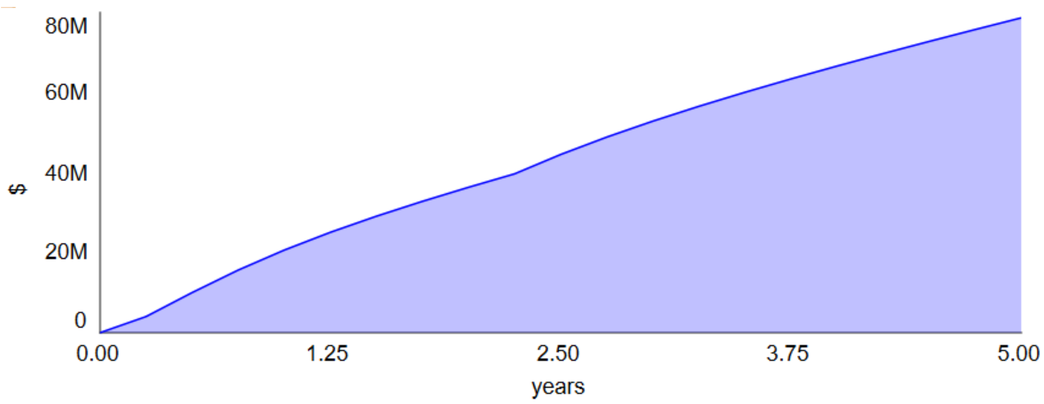

Figure 4-2 Increase in the Enterprise Value

Overall Evaluation of the Case Study: Managemental Insights

Applying a system dynamics model in the mining sector provides critical insights into investment decision-making processes. The model's focus on demand forecasting highlights the need for companies to remain agile and responsive to market fluctuations. For instance, the projected demand for minerals, particularly copper, underscores how external factors like GDP growth and other trends like population can significantly impact investment strategies. Companies should closely monitor these variables to anticipate demand shifts, ensuring that exploration and resource allocation align with market needs. By leveraging this demand data effectively, stakeholders can make informed decisions that enhance profitability and competitive positioning.

Furthermore, the exploration decision component of the model emphasizes the importance of maintaining exploration capacity as a part of the company's growth strategy. The decision to uphold a consistent exploration rate reflects a balanced approach to risk management, allowing companies to adapt to future opportunities while safeguarding existing assets. This strategy not only supports long-term sustainability by replenishing mineral reserves but also positions companies to capitalize on market conditions that favor resource development. By prioritizing exploration, firms can enhance their operational resilience and secure a steady supply of valuable minerals, which is vital in a sector characterized by uncertainty.

Finally, the model's insights into enterprise value demonstrate its significance as a key performance metric influencing investment decisions. By linking enterprise value growth with operational performance and market conditions, the model provides a comprehensive framework for assessing project viability. Companies should leverage these insights to evaluate potential investments critically, ensuring that anticipated enterprise value aligns with the company's growth strategy. As illustrated in the model, exceeding expected enterprise value can serve as a solid signal to proceed with investments, thus enabling firms to optimize their portfolios while adapting to the dynamic landscape of the mining industry. In summary, integrating system dynamics into investment decision-making fosters a more proactive and informed management approach, which is essential for navigating the complexities of the mining sector. A company can strategically allocate its resources by comparing multiple projects to optimize investment returns. Consequently, this system dynamics model enhances the investment decision-making process by identifying which projects align most effectively with the company's growth strategy and financial objectives.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the mining industry, investment decisions throughout the various stages of mineral property development are challenging due to inherent uncertainties characteristic of the sector. Consequently, an investment decision model must comprehensively address all aspects of the decision-making process. System dynamics modeling has yielded significant insights into the complex investment decisions within different industries. This study aims to reveal the underlying dynamic complexities of this decision-making process by applying a system dynamics model.

The developed multi-submodule system dynamics model offers comprehensive insights into company growth and investment decision-making stages. Specifically, this model incorporates five subsystems: valuation, production, growth strategy, demand, and finance, integrating insights from industry experts and relevant literature. The methodology of the study encompasses four critical steps: (i) identifying the investment structure, functional dependencies, and boundaries by decomposing the system into its components based on both subjective and objective data; (ii) developing an investment decision model within a system dynamics (SD) environment by establishing system configuration, decision model boundaries, and interdependencies; (iii) implementing a case study to optimize the identified parameters using a monitoring and reporting system; and (iv) conducting output and sensitivity analyses for various investment decision scenarios with differing parameters.

This system dynamics model was applied to a hypothetical copper mine investment decision involving an operational mine with a processing capacity of 850,000 tons per annum and an average copper mill head grade of 1%. The model was calibrated using publicly available data, including annual reports and industry news related to mineral property transactions at different stages. Following debugging, the model was simulated over five years with quarterly time increments to align with standard financial reporting practices, facilitating the analysis of changes in enterprise value every quarter.

The results indicated that the company's enterprise value was estimated at 78.9 million USD, with a target growth rate of 11.2%, which are compelling figures for investment in mineral properties. Various factors, including operating and capital expenditures, influence free cash flow. Whether utilizing debt or equity, the company’s capital management policy significantly impacts its available free cash flow. Furthermore, market conditions play a crucial role; operating expenses tend to increase substantially over time in high-inflation environments, leading to a dramatic decline in free cash flow. Mineral reserves, as a vital component of a mining company's assets, are essential for sustaining revenue. This study suggests that the company's mineral reserves are projected to grow over time based on the provided inputs, indicating that it can continue its growth trajectory using its existing reserves without exploring new properties until resource depletion is approaching.

The current model can be applied across various stages of mineral property development and for different mineral types to identify the optimal alternatives among investment choices. Consequently, mining investors may utilize the developed system dynamics model to determine the most profitable and strategically appropriate options, thereby integrating it into their existing investment decision-making processes.

5.2 Recommendations

A comprehensive system dynamics decision model was developed to enhance investment decision-making in mining investments. This research can be further improved by considering the following recommendations for future studies:

i. Alternative valuation methods can be incorporated, such as appraised value and the comparable transactions method.

ii. The model can be specialized for mining investments in different market environments such as developed, emerging, or undeveloped.

iii. Future studies may benefit from incorporating survey-based data. It may provide a more dynamic and up-to-date representation of the mining investment decisions and priorities of the mining company executives, enabling researchers to capture evolving trends and respond promptly to changing conditions in the investment side of the mining industry.

iv. The model can be enhanced by incorporating behavioral aspects of investment decisions to understand better how these choices are influenced by the cognitive and emotional factors inherent in human decision-making processes.

v. Future models could better incorporate the supply and demand dynamics of specific minerals or metals in the global market to understand their influence on investment decisions and project valuation.

vi. Additional constraints and variables related to operational and investment vulnerability can be incorporated into future models, including detailed modifying factors, market selection, top management experience, and company culture. This integration will enhance the understanding of investment decision-making within the mining industry.

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