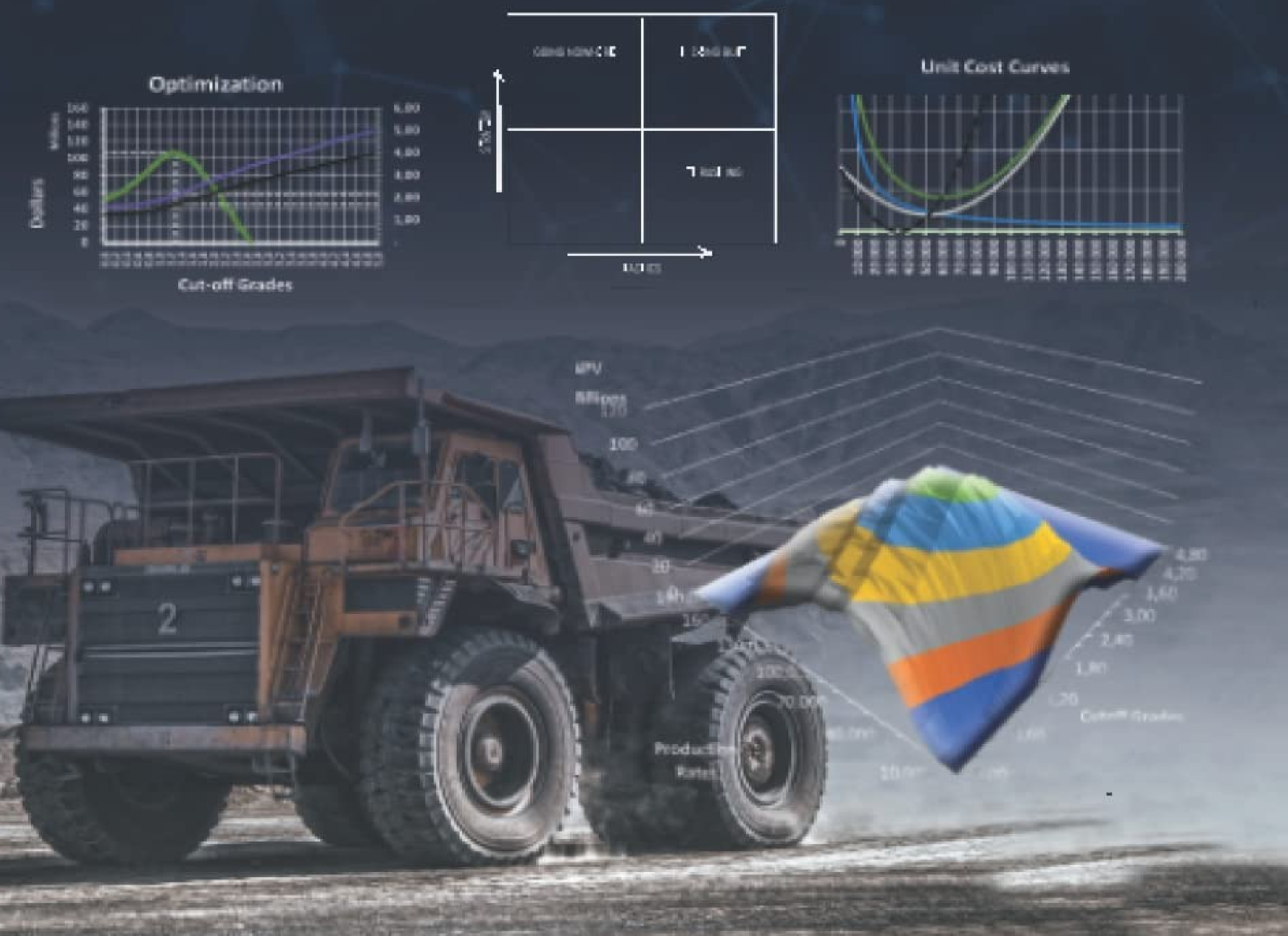
CRAIG HUTTON

Mining Economics EXPLAINED

A Guide for Boards, Executives, Managers and Investors



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Craig Hutton

craig.m.hutton@gmail.com

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Acknowledgements

The opportunity to work with great people and great minds started in the South African gold mining industry. Early in my career the industry experienced a massive change in mindset with respect to the business of mining and the primacy of the orebody. In the process, the role of the geologist was being elevated from useful to critical. Until then, the mining industry had been dominated by mining engineers who held sway.Mining was about tonnes, or in the South African vernacular, “stof”.

In 1994, a new era dawned as the gold mining industry saw and was still to endure the worst of falling gold prices as central bankers sold their gold holdings. To survive, a new way of thinking was demanded and along came a young, at the time, mining engineer who understood the importance of the orebody. His name, Bernard Swanepoel. By prioritising the orebody as the single most important area of focus and relentlessly pursuing cost discipline, he built the world’s fifth largest gold mining company in less than a decade.

Dan van Heerden, also a mining engineer, understood the significance of understanding and focusing on the economics of an orebody, and who was an early pioneer of the development of the ore optimisation algorithm utilized in this book. The focus was firmly on maximising cash flows from orebodies being mined. Out went mining to the pay limit and in came mining to the cut-off grade that yielded maximum cash flows. These two gentlemen had a profound influence in the formulation of this book.

Professor Richard Minnitt, who taught Mining Economics at the Witwatersrand University and whose work forms a bedrock applied to mining economics in this book, is another stalwart and whose work hopefully finally finds widespread adoption. Others who must be considered who have contributed to the collective knowledge base include Isobel Clerk, the world-renowned geostatistician and whose very practical approach to statistics and real-world challenges has shaped a keen understanding of ore deposit estimation. Carel de Jager retired but who served as the Technical Investment Review Manager for Anglo American plc and with whom the author worked closely over many years and who always provided challenging feedback and provided great professional support and mentoring. Dr. Gordon Smith, Executive Head Technical Anglo Platinum, whose pioneering and lasting work on strategic planning and the implementation of project value tracking is show-cased in this book. Hakkies Griesel, who took the risk of being an early adopter and entertained the applied knowledge in this book. As a result, the knowledge of these concepts was converted into a sophisticated modelling technique combining algorithms that provide an automated platform for rapid recalculations to determine the optimal economic scale of mines and also for determining the current optimal economic efficiency of ongoing operations. Finally, for the many long hours of robust discussion with Andy Clay of Venmyn Rand fame. Andy has a wealth of experience with over 40 years in the minerals, oil and gas, and finance industries and has authored hundreds of public reports and valuations as a registered Competent Person and Competent Valuator and Qualified Reserves Evaluator.

About the Author

Craig Hutton, the author and veteran of 35 years in the iternational mining arena, holds qualifications in geology, economics and finance, as well as a Masters degree in Business Administration. The theoretical grounding combined with over 25 years of experience in applied mining economics serves as the foundation to the writing of this book.

He started his mining career with Anglo American as a student geologist in the late 1980s. He soon realized that he would need to do more than just study and practise geology if he wished to advance his career in management. So began his education and immersion into mining economics.

Craig has prolific international experience across all major commodities, having travelled to most mining jurisdictions in the world while practising mining economics. He has worked for major mining companies such as Anglo American plc, Placer Dome, Harmony Gold Mining Company and a plethora of small and mid-caps in his long mining career. He scaled the ranks starting as a junior geologist to being appointed as Group Chief Executive Officer of African Consolidated Resources. In addition to deep mining business knowledge Craig has a well-established knowledge of financial markets and capital fund raising.

Given his considerable appreciation for the significance of the primacy of the ore deposit, his considerable business acumen and an unrelenting focus on maximising investment returns, his craft was distilled over decades and much of this knowledge is contained in this book.

This knowledge base provided Craig with the keen insights to identify and then successfully deliver 3.5 million ounces of gold mineral resources with over 1 million ounces of ore reserves from the former Rio Tinto mine, Pickstone Peerless, in Zimbabwe. In just 14 months Craig directed and coordinated the Preliminary Economic Study, Prefeasibility and Feasibility studies that yielded a final result valuing the project at US$ 250 million in

2013 for a company with a market capitalization of just US$ 30 million at the time. The speed of the completion of these studies is testament to the power of the modelling techniques packed in the pages of this book.

Craig continues assessing mining opportunities internationally, working as the Head of Industry and Mining for an international metals trading business. It is Craig's hope in writing this book that he will make a meaningful contribution to maturing the field of mining economics.

Dedication

This book is dedicated to my wife who afforded me the kind patience and support over the course of writing this book. The many late nights and sacrifices encountered supporting me, I remain forever grateful.

Preface

This book is crafted against the backdrop of the commodities super-cycle that we had in the first decade of the 21st Century, and the mining industry having learnt severe lessons. Dr Ian Runge summarized the decade-long experiment with the prioritization of volumes and said, “The economics of mining is at an inflection point. For the last decade or so our focus has been on developing mines and bringing them into production. It is not production on its own that is important, it is how efficiently we can produce.”[1] The message was echoed by Ivan Glasberg, Chief Executive Officer (CEO) of Glencor at the time of penning this book: “The big guys really screwed up (during the super-cycle) by building too many mines”, and as a result he opined that miners needed to learn about supply and demand fundamentals. “The real trap in the gold industry in the past was chasing volume,” said Tom Palmer, Newmont CEO and, “No one made any real money,” according to Barrick Gold Corporation’s CEO, Mark Bristow.

Fast forward, and today growth is a dirty word in mining. Today miners are much more cautious and even gun-shy when they consider committing capital for growth. The hard lessons in economics from the last super-cycle resulted in many Chief Executive Officers (CEOs) being fired as a result of prioritizing production volumes, which resulted in budget blowouts, extended construction delays, a decade-long deterioration of returns on investment, and large overspending on acquisitions that ended in billions of dollars of impairments when metal prices softened. This made CEOs and boards reticent to repeat the mistakes.

Since then, the industry has focused vast amounts of energy on efforts towards renewed strategy innovation, cost reduction and cost discipline, capital rationing, improving productivity, debt reduction and portfolio optimisation, among other initiatives. Refocusing attention on these areas has had tangible benefits. “For the world’s top 40 miners, 2017 was a remarkable year. Thanks, in large measure to the continuing recovery in commodity prices, fuelled by general economic growth, revenues rose dramatically by 23%. At the same time, the cost saving strategies of the past few years delivered results, with margins and cash generating ability improved as well, leading to a sharp increase in profits. Capital expenditures remained flat. With liquidity concerns that were still lingering in 2016 mostly resolved, balance sheets strengthened. Companies had the flexibility to act. Across the board, a heightened focus on safety in operations, reducing leverage and avoiding aggressive investments in new capacity, indicates that management is proceeding in a measured and deliberate way,"[2] PwC reported (2018).

After all the hard work, miners are now understandably more hesitant to grow their project pipelines, take on debt and grow their resource and reserve bases, out of fear of market reprisal. This hesitancy has caused a new risk. In 2020, Bristow, speaking at the Johannesburg Mining Indaba, highlighted an urgent concern: "A reserve crisis in the gold industry now exists." Miners seem to be caught between a hammer and sickle. While market sentiment remains firm, reflected by Mark Burridge's[3] comment that, if the gold industry gets to the point of growth versus returns, then companies paying returns will be backed. Miners understand that growing reserves is the lifeblood of the industry. The market requires "miners … to maintain capital investment discipline and continue to assess each opportunity against consistent criteria. This means resisting the temptation to pursue acquisitions or projects at any price."[4] Miners well understand that "every single day that they take something out of the ground, that value disappears forever, and unless you do something to replace that value, you are going to end up withering and dying,"[5] said Sir Mick Davis. The challenge is to grow the business in a disciplined manner that will consistently maximize shareholders' returns or lose out on attracting capital investment.

How is this to be accomplished, exactly?

Mining is a complex business requiring significant and patient capital investment that must be rewarded to sustain a depleting pipeline. Mineral resources are exhaustible and therefore investment in new projects is required on a continuing basis to sustain a mining business. Capital rationing and capital discipline is a compelling focus if the intention is to maximise returns on investment. The common approach to mine development has been the adoption of a “one shoe fits all” approach, with little insight into the economic dynamics of the ore deposits being mined.

Ideally, a feasibility study would result in an optimised design for the mine and processing plant. Most studies, however, are constrained by time and budget and consequently focus on achieving a least regret outcome without really determining how much better the project could be. The 80/20 rule is argued, in the name of pragmatism, despite the fact that every project is chasing the same pool of money. This approach often leads to sub-optimal outcomes and significant opportunity costs. By recognizing that each ore deposit is unique and that it has a unique geochemical fingerprint, modelling its unique economic signature is a critical exercise in the effort to establish a mining project’s economic robustness and its ability to yield strong and consistent cash flows and dividend payments through the commodity cycle.

The key variables that miners control are the cut-off grades, production rates and costs. The selection and determination of these variables, however, cannot be divorced from a keen understanding of an ore deposit’s economic capacity. The primacy of the ore deposit is often ignored when time and budget constraints exist. As the world readies for the next commodity cycle, the overall strategy and planning process will need to identify which opportunities will give the best returns on investment, in order to secure investors’ support.

Following a review of the life of a mine, for MMG Rosebery Mine, the proposal to increase production from 0.8 million tonnes per annum to 1.2 million tonnes per annum, raised questions as to the seemingly arbitrary reasoning for the production increase. Primary among the questions asked were, “Does the proposal add value?” “Would the new production rate be sustainable?” “Was the best value adding configuration identified?”[6] “Orebodies are unique and more so with so much grade variation and accessibility of orebodies today”[7]. Before the three critical questions asked can be answered, the nature of the targeted ore deposit must be fully understood in economic terms. The scale of production has an impact on the grade delivered to the processing plant and that grade significantly affects the rate of metal recovery. To the author’s knowledge, there is no existing tool that considers in a complex way microeconomic principles that affect varying cost structures, cut-off grades, capital intensity as a result of varying scales of production and associated construction timelines, notwithstanding the optimal cut-off grades in a dynamic manner.

Lost in the maze of conversation are the contributions of Professor Richard Minnitt, et al. At the time of publishing his papers, the fashionable view in the mining and investment industry was volume growth at all costs. Miners were rewarded for the largest project pipelines and greater production of commodities, and it seemed that no one was overly concerned about optimising the economics of a mine. Minnitt suggested that mining people were unconvinced of the classical economic approach, despite the connection between classical economics and exhaustible resource depletion being well established. But then academics, he said, had not provided much in the way of usable concepts for making mining people better extractors and depleters of natural resources. Moreover, the ideas and concepts were often shrouded in complex mathematics that tended to detract from the application of those concepts. On the other hand, he added that most "post graduate students working in the minerals industry generally had a technical rather than an economic bent." Dr Ian Runge, the well-known mining economist of RMP Global fame, was quite clear about the place of economics in mining: "Skill in economics," he said, "Is an essential partner to technical skill at every step of the mining process and includes not just the most economical way of mining." An important point that he noted was that "… recognising the importance of something is not the same as providing the tools that achieve it".[9]

Since every ore deposit is unique, it follows that the economic capacity and yield differs from one deposit to the next. To maximise value, the planning process cannot start by optimising the mine design and plant that imposes a rate of production without first understanding the nature and capacity of an ore deposit. The starting point of any mine design must be to understand the intrinsic nature of the ore deposit.

By combining microeconomic concepts described by Minnitt and an orebody's economic grade signature, the author has been able to effectively determine, early on, an ore deposit's realistic economic viability against varying rates of production and varying cost structures. Welded together, this tool offers a rapid and robust approach to determining the optimal scale of operations, the rate of depletion and the optimal cut-off grade, defining the maximum economic value that a peculiar ore deposit can yield.

In keeping with this approach, this book takes an honest look at the outcomes of the last commodity boom and offers an alternative approach, consistent with the new mining mindset: Value over volume. Davey Bickford: "The industry may well experience another boom like the one we had in the first decade of the 21st century, but to forget the lessons of that particular cycle would be an amazing (not to mention unfortunate) feat. Markets can be frivolous. Demand and prices can shift on short notice. Today's investment in outsized production can become tomorrow's write-off. That is that why so many leaders in the industry are convinced that value, not volume, is the way forward."[10] The emphasis on value over volume is not to deny that volume has a place; rather, this book will set out a value discovery approach by determining the optimal scale and rate of extraction that an ore deposit has the capacity to sustain. It is about placing the orebody front and centre and allowing the orebody to dictate the economics.

The author's persuasion is that creating value is not a binary trade-off between value and volume. Rather, establishing the optimum variables that maximise value provides the C-suite, the line of sight to fully understanding the most robust economics that not only maximise value at a point in time, but sustainably through multiple commodity cycles if necessary. This book is purposefully short on complex mathematics and long on useable tools and techniques. Those stimulated by mathematics will likely be disappointed as the aim and intention is to provide and describe a useful and robust classical economics toolkit that has proven application in the field with regard to addressing the need for a modelling technique that can help miners address the designing of mines that optimize capital investment and maximize returns.

These concepts are not all my own, although the author has diligently over many years sought to harmonise a knowledge base and contributions of others into a sensible approach that will unfold in the pages that follow.

Accordingly, other authors are quoted liberally because we truly do stand on the shoulders of giants, and to acknowledge less is simply a journey of unadulterated arrogance.

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2. (PwC, 2018)

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4. (PwC, 2018)

5. (Engineering News, 2020)

6. (Mining Scenario Analysis and Mine Variable Value, 2014)

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– Should “economics”, ““exhaustible” and “resources” be in upper case?

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Chapter 1

Introduction

"The ultimate test of corporate strategy, the only reliable measure, is whether it creates maximum excess economic value for its shareholders."

– Alfred Rappaport (1998)

I. The Backdrop

> Mining Returns
>
> Of all those expensive and uncertain projects, however, which bring bankruptcy upon the greater part of the people who engage in them, there is none perhaps more perfectly ruinous than the search after new silver and gold mines. It is perhaps the most disadvantageous lottery in the world, or the one in which the gain of those who draw the prizes bears the least proportion to the loss of those who draw the blanks: for though the prizes are few and the blanks are many, the common price of a ticket is the whole fortune of a very rich man.
>
> Adam Smith, The Wealth of Nations (1776)

The great commodity cycle from 2003 to 2013 started off on a positive trajectory, but in the end it proved to be a costly affair for the global mining industry and its shareholders and stakeholders alike. The industry prioritised operational scale and increased production throughput, in the belief that greater economies of scale would realise significant and sustainable gains in productivity and significantly lower unit costs of production. Ergo, the goal: To be a first quartile industry cost producer. Achieving this goal by prioritising greater and greater production output, a company would realise significant competitive advantage, relative to its peers in size, productivity and costs. Size would also benefit costs by a company's greater purchasing power and thereby drive down input costs further through sheer purchasing power. This was the basic premise of the mining industry at the time.

This belief was sorely tested by a decade of high prices that concealed the impact of rampant inflation, falling productivity and poor capital discipline in the sector. Fast growth in mining output fuelled demand for mining services and inputs, such as explosives, diesel, rubber tyres, plastic pipes, chemical reagents, rock drills and haul trucks, etc, creating a tight supply market and driving prices up. The industry also faced a critical shortage of skilled workers across the board, leading to intense competition between miners, and elevated labour costs to meteoric levels. Despite this pervasive view: Go Big or Go Home, the economic advantages were not convincing and proved to be fleeting and short-lived at best.

As metal prices collapsed, companies were trapped in a brutal vortex as accountants began impairing assets, sending share prices into a tailspin. To appease the investment gods, many a mining chief executive officer was forced to walk the plank. Ironically, the very same investors who had previously encouraged and cheered these executives on to build the biggest project pipelines, and the largest mines, now demanded retribution. Poor cost discipline, poor productivity, overpaying for projects, high debt levels on the balance sheet, misguided capital allocation and spending was evidence of a clear lack of understanding of basic business principles, and warranted action against CEOs. Hastily, boards appointed a new breed of chief executive, ones said to better understand the demands of the investment community and who had a better grasp on business. Consultants descended on the industry in droves, with their financial metrics tool kits and a new belief in “right-sizing” capital projects and a view on what “sustainable” cost reduction really meant. The mining industry was encouraged to adopt a new mindset, one that was open to the possibility that past methods may not yield the most promising future results. The new era of executives turned to the well-scripted, well-versed playbook of retrenchment. They scrambled to reduce headcount, deferred capital expenditure, and began a vigorous campaign of debt reduction, partly accomplished by selling projects thought to no longer suit a more focused project portfolio. A renewed focus on productivity and shareholder value was once again touted as the panacea for the industry’s resurrection from the ashes.

Fast forward, and PwC reported that by the end of 2018, things looked good for the world’s top miners. The world’s forty largest miners consolidated their performance as they increased production, boosted cash flow, paid down debt and provided returns to shareholders.[2] Yet this ignored that by 2016, well after the new cadre of deployment had happened, the mining industry had given back all the value created during the Chinese growth cycle[3]. It begs the question as to whether it was price or retrenchment actions that were responsible for the improved results. Yet a cloud still hung over the industry, as still in 2018 the mining index barely held its own against global market indices, despite strong financial performance.[4]

By 2020 the tide had firmly turned, but a new dilemma now presented itself. Mark Bristow, chief executive of Barrick Gold, said that, “Reserve crisis in the gold industry now exists.” Given all the focus that preceded 2020, constrained miners were unable to invest in bread-and-butter activities such as resource replacement.

The aforesaid is perhaps an overly harsh narrative of the mining industry, but it does hint as to the many complexities that exist and that turning the ship is fraught with difficulty. Just as once crisis abates then another appears. Mining is fundamentally a complex long-cycle business that requires significant amounts of capital, a high degree of technical skill, business acumen and keen understanding of economics. The mining industry is quite different to other industries and best characterised by Dr Ian Runge[5]:

1. Every mine is different because every ore body is different.

2. Mining is a capital-intensive industry with high capital costs.

3. Large scale mining requires continual injections of capital to maintain production.

4. Knowledge is high cost and decisions are made on imperfect information.

5. As a primary industry, returns are extremely sensitive to booms and busts.

6. The product produced relies on estimates and probability predictions rather than certainty.

Additionally, and importantly, ore deposits are exhausting assets. The industry is engaged in the very real management of scarce resources and therefore there is no second chance if or when mistakes are made. Against this complex backdrop, miners must run a business and return value to shareholders who provide the risk capital.

ii. The Primacy of the Ore Deposit

“Ore deposits are often referred to as valuable resources. In a sense they may be, but regarding them as such can be misleading. They are certainly not a valuable resource that might be compared with cash in a bank or even a crop on the ground. The only immediate value they could possess is the price a mining company might bid for the right to mine them. Any value that might be ascribed to the mineralisation is then realised as an integral part of the proceeds of the operation. Only a mining operation earns revenue and incurs costs, and it therefore is the economic entity that can have estimated value that can be ascribed to it. This value is clearly dependent upon the definition of ore, with some bases of definition giving rise to higher values than others. The basis which generates the highest value is optimum and this basis establishes the economic definition of the ore. In other words, material from the mineralised body should be scheduled for mining as ore, if and only if, the decision to treat it adds to the overall economic value of the operation. This is the crucial criterion.”[6]

This understanding and determination leads naturally to the big debate of: Value versus Volume. A fierce debate has raged in the mining industry as to how much material must and should be mined from an orebody. In the early part of the 21st Century, the volume game was tested and production output was prioritised. Belying this conviction, was the rationale that to “maximise return on investment, both the capital investment per unit of output and the operating cost per unit of output, should be minimised. In general, both cost measures decrease as the scale of the project increases, so the initial temptation is to “push the orebody to the limit.” In general, the tonnage capacity of the processing plant sets the rate of production. If the plant had been constructed with surplus capacity or expanded to that point, then great pressure is put on the mine to fill the mill, often with scant regard for the effect on the quality of the material delivered, because the significance of the grade-rate relationship has not been considered.”[7]

According to McCarthy, in the past both owners and mine designers have taken great pride in building plants that substantially exceed “name plate” capacity. The excess capacity was quickly converted into mine demand, with adverse results in that the average head grade fell below the planned grade, if not the optimal grade. It was a belief that “sweating the asset”, or more precisely running equipment at full capacity would enhance the accounting return on assets (ROA), reduce unit costs and increase productivity, which in turn would yield a higher return on investment (ROI). This idea is an over-simplification of a complex business, as it stems from a misunderstanding of the way in which minerals are distributed in the ground.

McCarthy, in a rather strident manner, says that engineers designing such outcomes are either incompetent or overly conservative, and by second guessing the economic optimisation of the ore deposit, owners are obliged to pay for something greater and more expensive. “The assumption that economies of scale will result from increasing throughput rates needs to be balanced by an awareness of the adverse effects of increasing the rate beyond a level that is supportable by the resource. For each scale of operation considered, it is a reality that for any intended head grade, at the associated intended cut-off grade, the actual head grade achieved, will fall as the mining rate increases. This effect is known to people at operations but is not recognised in current ore reserve estimation methodology.”[8]

Increasing throughput, however, does not necessarily translate into a reduction in unit costs. In economic theory, three possible outcomes exist when considering increasing the rate of production:

1. Unit cost of production goes down – economies of scale;
2. Unit cost of production stays constant – constant economies of scale;
3. Unit cost of production goes up – diseconomies of scale.

This equation is, however, further complicated when it comes to mining. As McCarthy points out, for each scale of operation, the intended head grade will fall as the mining rate increases. There are two measures that require attention when miners consider scaling up operations. The first measure is the cost of production based on ore tonnes processed, and the second measure is the cost of production of metal tonnes/ounces/pounds. It must be recognised that the cost of production is driven by the volume of ore processed, not the amount of metal or concentrate produced. Thus, and as is often the case, the unit cost of production of ore can fall, while the unit costs of per metal unit rises, due to a fall in the head grade at higher levels of ore throughput, wiping out any benefits of scale. Added to this, McCarthy warns, is that both technical and commercial risk increases as the scale of the project increases, and conversely. “The lower the production rate, the lower the required investment, the longer the income stream and the lower the risk to the investor.”[9] It is these dynamics that must be carefully considered by miners if they are to deliver results expected by the providers of capital. Failure to consistently deliver the required financial performance will risk the incentive for future investment.

McCarthy does, however, recognise that some excess capacity may be useful in responding to variations in resource grade or metal prices, but then the reasons for the excess capacity should be clearly articulated, and under which circumstance that excess capacity will be utilised. He suggests that what is needed, is a procedure that is “reasonably rigorous and transparent and that identifies any factors of conservatism built into the mine and process plant.”[10]

When excess capacity does not exist, Kenneth Lane says, miners must process ore that meets two criteria:

1. Mineralised material should be treated as ore if it will provide a contribution to profit;

2. Mining should be conducted in such a way as to maximise the extraction of valuable mineral.

These two points are, however, qualified by Lane and worth noting. “The first criterion in some form is popular among technical staff. The question of what constitutes a contribution to profit is the subject of much debate, however. It is often argued that any material for which the value of the recovered mineral will exceed the marginal cost of treating it, should be ore. Sometimes a contribution towards overheads is added to the costs and sometimes, beyond this, a minimum profit requirement is also added. The basis of the argument is that if such material is not classified as ore, then an opportunity to earn profit has been wasted. The flaw in the argument is that it totally overlooks capacities. It is equivalent to arguing that a retailer should add to his stock any goods which promise to yield a marginal profit. Retailers do not do this. They are all aware that space is limited and within this limitation they try to stock the more profitable items. Similar considerations apply to a mine. It has a capacity which is limited by some part of the installation – the shaft, the mill, the truck fleet, the rate of development, etc., and within this limitation it should choose to process the more profitable material. This policy is consistent with the interpretation of the criterion which includes a minimum profit margin, but the supporters of the criterion usually give no basis for determining the margin, other than company policy. The present value criterion, by contrast, gives a precise basis derived as a trade-off between present and future earnings, via the present value function.

The second criterion, namely that the extraction of valuable mineral should be maximized, is frequently proposed by mineral rights owners, local governments and conservationists. Of course, it immediately begs the question: what is valuable mineral? An extreme argument is that all the mineral or all the geological reserves (whatever they are), should be extracted in the interests of conserving resources. This is an unrealistic stance which usually stems from a misunderstanding of the way in which minerals are distributed in the ground. A less extreme view is that the mine should be developed in such a way that poorer material is extracted along with richer material in an acceptable blend, yielding a satisfactory profit. Of course, every mine of necessity blends poorer and richer material, and the point of a cut-off grade is to determine just how poor, poorer material can be. The protagonists of the maximum extraction criterion, however, usually imply a degree of subsidy for poor material which would not be economical on its own. What this means is unclear, but the idea of cross-subsidies of ore grades is economically unsound, except in special circumstances. A more reasonable view defines valuable material in the same way as in the first criterion. In this case, the two give the same result and suffer from the same objection about the effects of capacity.

Both criteria have another major shortcoming. They do not deal satisfactorily with price variations, nor do they deal satisfactorily with variations in other economic parameters, but price is the predominant influence."[11]

Determining what to mine is as important as to determine at what rate to mine. McCarthy concisely summarises the author's shared experience, "that mining, and processing rates are commonly set in the following ways:

1. To satisfy economic criteria (e.g., return on investment), often with inadequate regard to what the orebody will sustain;

2. To match existing installed capacity (e.g., when a pit is converted to an underground mine);

3. Using 'rules of thumb', such as the equivalent vertical advance rate limit, or Taylor's rule;

4. By detailed 'paper' or computer scheduling of mine production, to establish the physical limit, then designing at the physical limit or with some 'margin of comfort';

5. To meet corporate goals such as ounces per year of metal production.

Experience with feasibility studies and a survey of the literature have not given an example of a quantitative approach that optimises a production rate based on the physical influences on the mining process. There may be an assumption by metallurgical and process engineers, that the mine planners have ways of optimising the rate, or alternatively that they can deliver whatever rate is needed to meet economic criteria. Neither assumption is true. Ideally a study should be undertaken to optimise the design of the mine and processing plant with regard to the dependency of head grade on the processing rate in order to establish the economically optimum to maximise value."[12]

"As has been stressed already, every mine is established on a body of mineralisation which is ultimately of limited extent. Some are very localised and are mined out in a matter of months; others are vast with seemingly endless sources of ore. Nonetheless, they are finite and, sooner or later, will be depleted. This characteristic makes the analysis of operating strategies for mines quite different from the analysis for most other industrial or commercial undertakings. The fundamental concept of optimisation by maximizing present values is just as relevant. However, other undertakings are not usually based upon an exhaustible resource and, hence, current operating strategies do not react on the future in the same way. For a mine, higher mining rates will shorten the life, and vice versa. The effects of this must somehow be built into the analysis. It is, of course, the present value function itself which provides the means for making cash effects, which occur at different times, commensurate. Present value is the only criterion which does incorporate a means for dealing with varying economic conditions. Parameters defining the conditions are included in the present value estimates and affect the optimum cut-off calculations in a way which avoids the nonsensical."[13]

“If there is no restriction on the available capital, then corporate value is maximised by maximising the Net Present Value (NPV) of every available viable project, and carrying all of them through to production. In the real world, where available capital is restricted, the corporation must select projects for investment using some ranking technique. Economic theory says that projects should be ranked using the Present Value Ratio (PVR), which is the ratio of NPV to initial capital investment. If the perceived risks are similar, projects with higher PVRs are selected before those with lower PVRs. A project with a high NPV but a low PVR may require more capital than the corporation (or the investment community) is able or willing to risk; or if developed, it may displace alternatives which would have provided a better aggregate return on investment. From the above, the mining rate should be optimised to maximise the project NPV at the corporation’s agreed discount rate, if this leaves it with a PVR that will make it an attractive investment. Arguably, the mining rate should be changed (and possibly reduced) to improve the PVR, even at the expense of NPV, if this will allow the project to proceed in competition with others. This observation emphasises the importance of right-sizing the operation, rather than pushing throughput into the limiting range.

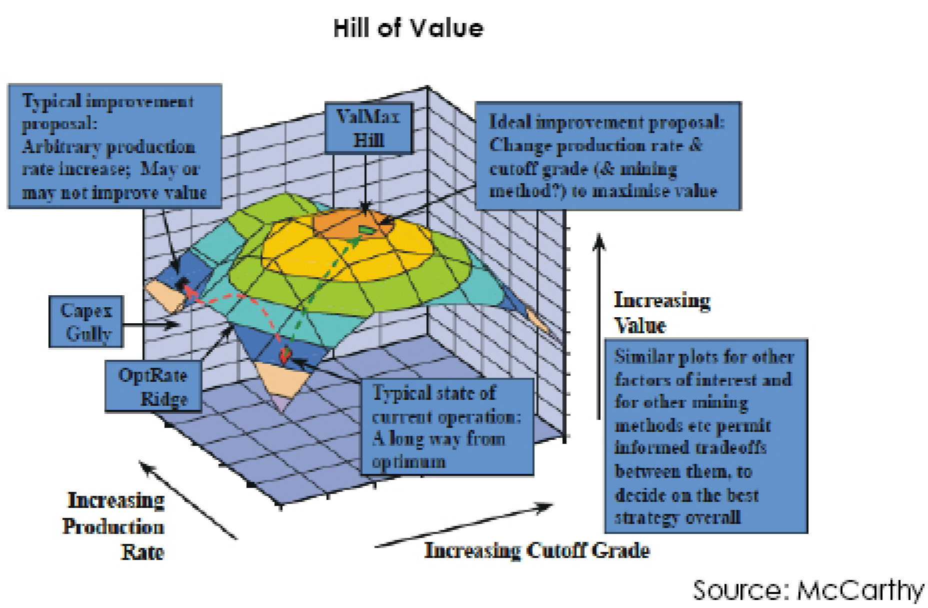

Figure 1: Finding and Climbing the Hill of Value

For each size of operation considered, it is a reality that for any intended head grade, at the associated intended cut-off grade, the actual head grade achieved will fall as the mining rate increases. Once recognised, this dependency of grade on mining rate has a profound effect on mine planning."[14] Figure 1 shows the relationship between mining rate and cut-off grade and its impact on valuation metrics (NPV, PVR or IRR). It is possible, therefore, to optimise the key parameters of mining rate and head grade to maximise value.

To that end "The grade-tonnage curve is an essential tool in mine planning, allowing the designer to choose a small, high-grade option or a large, low-grade option, or any option in between these limits. For each option there is a set of corresponding cut-off grades used in planning and operations. The size referred to here is the tonnage of ore that can ultimately be extracted from the resource." A chapter is dedicated to the grade tonnage curve in this book, given its importance and centrality for optimisation modelling described in this book.

iii. From Concept to Application

Runge makes the point that "recognising the importance of something is not the same as providing the tools that achieve it". The motivation for authoring this book is to address this. In doing so, the work of Dr Richard Minnitt, which describes that application of microeconomic costs curves at the individual mine level, is also considered. Minnitt has commented that, "Annually the content and relevance of the postgraduate course in Mineral Economics in the School of Mining Engineering at the University of the Witwatersrand is reviewed. The connection between classical economics and exhaustible resource depletion is well established, but at the end of teaching such a course, especially to mining people, the benefits of the classical economic approach seem less convincing. The reason for the concern is that the extensive literature on the theory of exhaustible resources is evidence of its interest to academics, but it does not provide much in the way of usable concepts to make mining people better extractors and depleters of natural resources. Postgraduate students working in the minerals industry generally have a technical rather than an economic bent."[16] He concedes that often complex mathematics gets in the way of widespread adoption, as the tools used to convert these concepts into useable models, if any, exist in thin supply.

The fact that miners' have a technical rather than an economic bent makes them less interested in economic concepts for the sake of learning new concepts. They are more likely to adopt economic principles when tools are made available to them, than convince them that they can be better and make more informed decisions.

Fundamentally this book sets out to describe a tool that relies on robust economic concepts and techniques to optimise the mining of an ore deposit, and to provide a critical line of sight as to the sensitivities of the deposit when changes to the critical variables are considered. By combining the unique signature of an orebody, described by a grade tonnage curve, and welding this to classical microeconomic cost curves, augments the work done by McCarthy in developing a Hill of Value, by providing miners insights as to how cost structures critically influence tactical changes to plans. Such a tool being largely elusive until now.

Beyond this, the modelling technique highlights the influence of discount rates and the size of the ore reserves on the rates of mineral extraction when varying the discount rates.[17] Ultimately, the quest is to determine the production "sweet spot" that considers an ore deposit, inherent economic DNA and its capacity to yield outputs that maximise well defined economic criteria. By determining the most profitable economic scale of operations, miners are better positioned to design mines that avoid the mistakes of the past and avoid the temptation to invest in over-capacity. The temptation will be greatly diminished when the impact to value creation is more clearly seen as average head grades are traded off against higher rates of processing.

The C-suite will also for the first time have direct line of sight as to what each mineral deposit can reasonably yield and then be positioned to instruct mine planners as to the exact economic parameters to be used in the mine design and architecture. This tool will likely be an essential part of a miner’s strategic tool kit.

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Chapter 2

Lessons of the Last Commodity Super

“The single-minded pursuit of production was destructive to margins and valuations.”

– Jamie Sokalsky

Preview

The last super-cycle (2003 to 2013) was a learning curve for the global economies and investors, with several lessons learned for the mining industry in particular. The emergence of China at the beginning of the millennium as a significant and growing consumer of mining products, saw commodity prices soar, spurring miners into action to create the biggest mines and the largest project pipelines. The focus was on getting products out as quickly as possible to meet the growing demand and to position themselves first in line[1]. A conscious decision to prioritise and pursue increased throughput and higher output was premised on the belief that this would drive down unit costs of production and increase productivity as an economies of scale strategy.

Fast forward to 2013: weak commodity prices, coupled with elevated costs, squeezed margins into negative territory. On reflection, during the decade long super-cycle, the benefits of prioritising production output and the investment benefits envisaged were not realised. The inertia of the negative trends was so great that by 2016, the mining industry had given back all the value created during the Chinese growth cycle.[2]

“The industry may well experience another boom like the one we had in the first decade of the 21st century, but to forget the lessons of that particular cycle would be an amazing (not to mention unfortunate) feat. Markets can be frivolous. Demand and prices can shift on short notice. Today’s investment in outsized production can become tomorrow’s write-off.”[3]

It is, therefore, worthwhile considering, in a dispassionate way, the super-cycle decade with the wisdom of hindsight to try to clearly understand what went wrong, and why.

KEY CONCEPTS

- 2003 to 2013 Commodity Boom Scoreboard
- Lessons from The Commodity Cycle
- The Primacy of the Orebody

I. 2003 To 2013 Commodity Boom Scoreboard

Global Mining Industry Top 40 Mining Companies Scorecard

Metrics	2003	2013	2106	2003-2013 % Change	2013-2016 % Change
Revenue	110	512	353	365%	-31%
Costs	81	350	251	332%	-28%
Operating Profit	29	162	102	459%	-37%
Tax	3.00	30.00	15	1000%	-50%
Net Operating Profit After Tax	26	132	87	408%	-34%
Investing Activities	20	125	40	525%	-68%
Free Cash	8	-6	-6	-175%	0%
Impairments	0.01	57	19	569900%	-67%
Interest Expense	3	15	9	341%	-40%
Implied Interest Paid	3.0%	2.4%	1.6%	80%	67%
Assets	223	1256	1063	463%	-15%
Debt	114	624	563	449%	-10%
Equity	109	632	491	480%	-22%
Debt to Equity Ratio	104%	99%	115%	95%	116%
Return on Equity	11%	3%	3%	-72%	-3%
Return on Assets	5%	2%	1%	-71%	-11%
NOPAT % of Revenue	24%	26%	25%	9%	-4%
Free Cash % of NOPAT	31%	-5%	-7%	-115%	52%
Free Cash % of Revenue	7%	-1%	-2%	-116%	45%

Source: PwC Annual Mining Reports

Table 1: Key Performance Metrics of Top 40 Global Miners

II. 2003 TO 2013 COMMODITY TRENDS

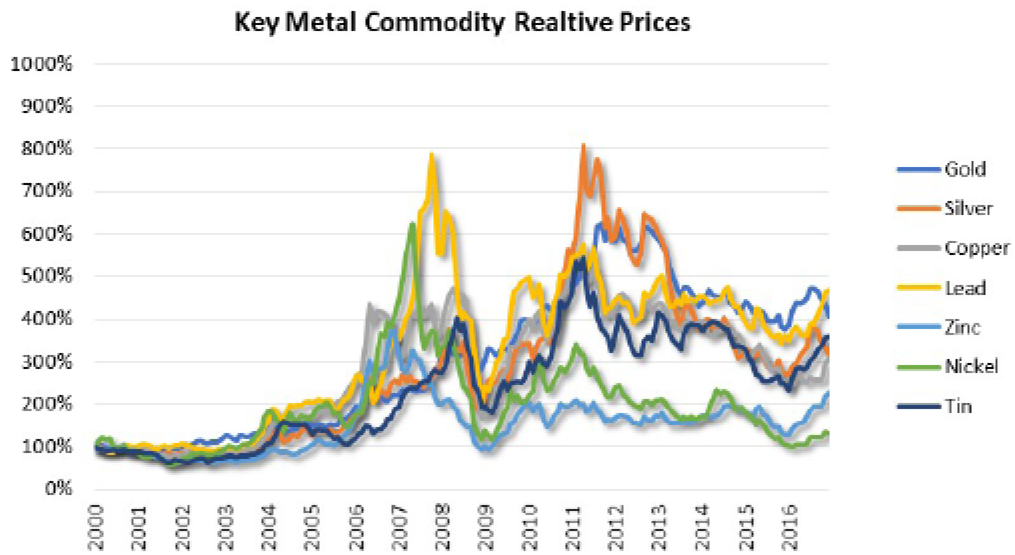


Figure 2: Metal Price Trends 2000 To 2016

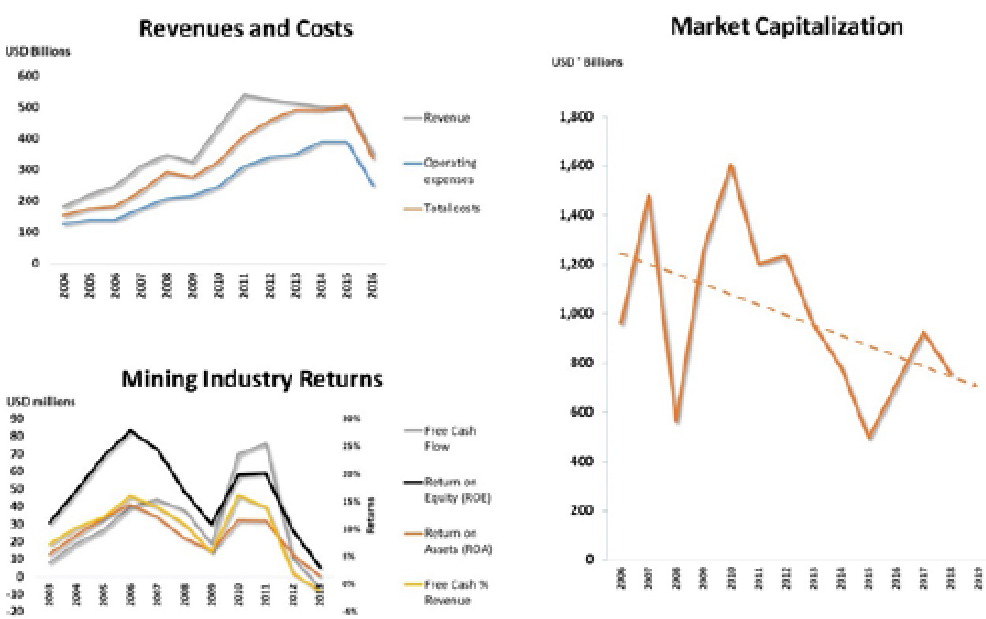
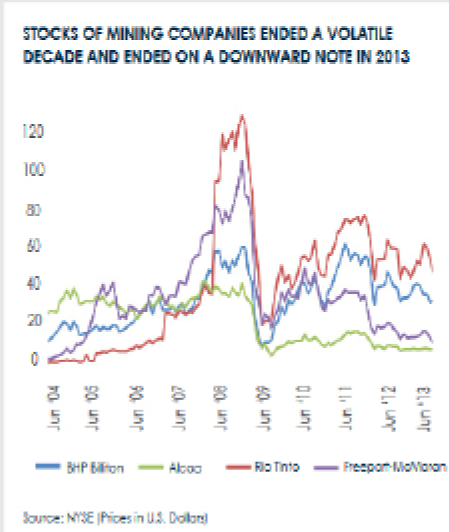


Figure 3: Top 40 Mining Companies Financial Trends

The commodity super-cycle of 2003 to 2013 was characterised by high metal prices across the metals commodity basket and illustrated in Figure 2. This represented an unprecedented opportunity for investors to claw back returns after the contraction of the mining industry in the 1990s. The hard work undertaken by miners to increase productivity, drive down costs and maintain a disciplined approach positioned the industry to reap the rewards as metal price gains gained momentum. As a conscious strategy, miners then prioritised volume, to capture higher returns to capture further benefits of economies of scale. The scoreboard, Table 1, shows that revenue, operating profit and net operating profit after tax all rose in quantum over the decade. Revenues rose by 365%, while net profits after tax rose by 408%. Tax payments increased 10x, while investing increased by 525%. By all accounts this performance was positive and a direct result of prioritising volumes, despite costs rising 332% during the same period. Share prices for many mining companies enjoyed a positive knock-on effect and steadily rose. Figure 4 shows the share price growth of four of the major mining companies' share price performances. Rising share prices were indicative of equity flows into mining stocks, which saw equity on the balance sheets rise by 480% for the top 40 mining companies over the decade. Similarly, the consolidated assets on the balance sheet increased by 463% over the period, while the debt-to-equity ratio fell from 5% during the period, despite debt increasing by 450%. By all accounts, miners had successfully executed their mandate.



RECKLESS ACQUISITIONS BY MINING FIRMS IN THE 2000'S HAS RESULTED IN MULTI BILLION DOLLAR WRITE-DOWNS

COMPANY	WRITE DOWN IN $ BILLIONS
Rio Tinto	14.4 billion related to aluminum and coal businesses
BHP Billiton	$3.3 billion related to shale gas and $3 billion related to nickel business
Kinross Gold	$3 billion related to gold mines
Tata Steel	$1.6 billion related to steel business in Europe

Source: Thomas White International

Figure 4: Impairment Write Downs

Curiously, and despite encouraging and supporting the mining industry in prioritising volume and building large project pipelines, by 2013 the market was looking for changes to management teams. The end of the commodity cycle was marked by acrimonious exchanges about miners' inability to successfully run their businesses profitably. Investors sought changes, starting with the dismissal of 50% of the Top 40 CEOs. The market believed that these CEOs had neglected to maintain strict cost discipline, had over-leveraged their balance sheets, had allowed productivity to fall to unacceptable levels and had insufficiently rewarded shareholders with dividend flows.

By 2013, came realisation that the impact of unconstrained project development now threatened to push commodities into oversupply, and with that the market anticipated the fall of metal prices. As metal prices softened, balance sheets were being impaired. PwC records that a $101 billion impairment charge was passed for the top 40 mining companies during 2012 and 2013, compared to an aggregate of only $28 billion from 2009 to 2011. The consequence of this was that market capitalisations began spiralling downwards on the back of an already well-established downward trend. From the peak in 2010 at $1.6 trillion, market capitalisations pivoted downwards to touch $783 billion by the end of 2014. Compounding this, were concerns that many producers found themselves on the wrong side of the marginal cost curve, something that could not ordinarily be sustained for extended periods[4]. The difficulties of slowing the inertia of an over-supplied market and what now seemed to be out-of-control costs, fuelled a swift market response. Figure 3 describes the industries performance most succinctly across revenue and cost growth to returns on investment and market capitalisation. The decade long profile was dissapointing at best.

A decade earlier, Dr Ian Runge had stated that, “The economics of mining is at an inflection point. For the last decade or so our focus has been on developing mines and bringing them into production. It is not production on its own that is important, it is how efficiently we can produce.”[5] In the drive to increase volumes, “mining companies worldwide largely lost sight of productivity goals that had underpinned operating discipline in the lean years of the 1980s and 1990s, when parts of the industry had set a healthy record in productivity improvement.”[6] Between 2004 and 2013 “mining productivity, as measured by MPI, has declined 3.5% per year, meaning that mining companies [were] 28% less efficient in digging and moving a ton of total material today, than they were ten years [before]. The pronounced decline in productivity [was] evident across different commodities, including copper, iron ore, coal and platinum group metals. It [was] also in evidence across most mining players and all the major mining geographies."[7]

A closer look at the financial efficiency performance over the period, however, reveals a telling trend. Despite the growth in revenues over the decade, by 2013 the mining industry's total costs had outpaced revenue growth. The average compounded annual growth rate (CAGR) for total costs was 12% for the decade, while for revenue growth it was 11%, according to PwC data on the Top 40 mining companies. By 2013 the total cost curve had caught the revenue curve, pushing margins into negative territory. This inflexion point happened to coincide with the sudden fall off in metal prices.

Had the industry simply ignored these trends? Did the industry lack the discipline or the agility to respond? During the first three years of the cycle, all financial metrics were up, including Free Cash Flow (FCF) , Return on Equity (ROE) and Return on Assets (ROA), as illustrated in Figure 3. Thereafter and in 2006, the trends turned negative. "By 2013, at $11 billion, the industry's Free Cash Flow had reached the lowest level since PwC's inaugural Mine (report) in 2003, only to be followed a year later with the industry posting negative $6 billion. The year-on-year decrease of 85% was larger than the biggest previous decrease of 50%, experienced in 2009." Operating cash flows in 2013 decreased 23%, to $137 billion, setting a record for the largest year-on-year decrease, beating 2009, which followed the global financial crisis. The downward trajectory continued, only troughing in 2016, at a low of $89 billion for operating cash flows.

Despite these trends, miners continued reinvesting operating cash flows into production capacity. On average, 95% of operating cash flows were reinvested into project development and new acquisitions, leaving little for shareholders in the form of dividends. In 2012, the industry's investing activities were at 32% of revenues, and set a record of investing cash into projects. At $169 billion it was notably far more than the 10-year average for the Top 40.

With the perfect wisdom of hindsight, it is apparent that during the heady days of the super-cycle, while the boom years roared and share prices soared, investors were content, and miners satisfied themselves that their strategy of prioritising volumes was working. Everyone was making money. It seems that little attention was given to investment efficiency as billions were ploughed back into projects, in an environment that had become increasingly costly to buy new projects and/or to own and run these projects. What seemed to be a virtuous cycle in the beginning had become a treacherous spiral. Individual CEOs were in a zugzwang and none were too bold to call the party over, even in the face of over supplying the market. Ironically, and not lost on the mining industry, it was the same investor base which had pushed for fast growth and rewarded those that had the most attractive growth pipelines, that then called for severe capital austerity while also demanding immediate investment returns in the form of dividends and share buybacks."[8], when the inevitable cliff edge had been reached.

III. Lessons From The Commodity Cycle

● Reflecting on what went wrong, Jamie Sokalsky, former President of Barrick Gold, reflecting on the lessons learned from the commodity super-cycle, commented that, "The industry is only now beginning to recognise that the single-minded pursuit of production was destructive to margins and valuations."[9] "The big guys really screwed up," said Ivan Glasenberg, Glencore CEO. "We've always been wanting to keep building and keep putting the cash which we generate into new assets. That's what we've got to stop doing as a mining industry. We've got to learn about demand and supply."[10] Perhaps the most prescient being that markets can be frivolous. Demand and prices can shift on short notice. Today's investment in outsized production can become tomorrow's write-off."[11] Lee Hodgkinson, of

KPMG, suggested that mining companies need to look at their businesses with fresh eyes and focus on finding the right balance between optimising current operations and preserving their agility to grasp future opportunities.[12]

Stuart and Spencer, in collaboration with the Centre for Copper and Mining Studies (Cesco), succinctly listed 12 key lessons learned from industry leaders, being:

1. Do not forget: cycles don't last forever; 2. Ensure rigorous, long-term planning; 3. Never lose sight of core balance sheet discipline; 4. Boards need to be balanced, experienced and firm; 5. Do not get distracted: focus on operational excellence; 6. Do not delay innovation and technical change; 7. Beware of growth at any cost; 8. Less haste, more speed;

9. Build in-house expertise;

10. Hire fewer, but better people; 11. Make your company worth working for, in the good times and bad; 12. Embed sustainable development in the business model.[13]

These points, however, do not consider the lessons learned from the market backlash. The market perspective was that, "Over-optimistic forecasting and planning fuelled runaway costs of building and operating mines, and focus on output resulted in lower mined grades, serving only to further inflate production [unit] costs and deepening profit margin squeeze."[14] As a consequence, miners lost focus on disciplined cost control and productivity and capital allocation, and had overleveraged their balance sheets. The market anxiety by the end of the commodity boom was that the project pipeline and new projects could not be turned off to respond to the looming oversupply, which would further depress prices.

In the aftermath, leadership teams were encouraged to invest time in understanding a mine's current performance and their strategy and how it impacted return on capital and profitability. McKinsey highlighted that, "A handful of companies, prompted by new leadership, short-term cash flow challenges or aging assets, sharply improved cash flow and increased the value of their assets by stepping back to rethink their strategies. Many [were] able to reverse the negative spiral and unlock new value from existing assets by reconsidering the scale of operations, which led to reduced capital investment and significantly lowering risk and realising earlier payback. Mistaking volume for value, mining companies traditionally viewed commodity volumes as the main measure of their success. Leadership teams were preoccupied with the engineering challenge of getting as much ore out of the ground as quickly as possible. Companies that assumed higher volume would automatically generate higher value, and once mine strategies are set, often continue down the same path without re-examining key assumptions. Frustrated, some firms have unloaded poorly performing assets, only to see a nimble rival generate far better returns with them ... but producing lower volumes may yield higher returns."[15]

Runge also urged that miners need to avoid the temptation to blame "metals price unpredictability and orebody characteristics, [that] have in many cases been inappropriately used as excuses for underperformance. Even when these unpredictable elements are real, the opportunity for mine design that is less sensitive to such change has frequently been overlooked."[16] What Runge alludes to, is the primacy of the orebody being mined. Ore deposits are not homogeneous, they are all different. While there may be many similarities, each has a unique and defined economic signature that needs to be fully understood. Appropriate ore body knowledge is critical, and this knowledge will be increasingly required to stand between failure, or success of some mining operations.[17] The valuable role of tools to provide the platform for greater line of sight as to the economics of an ore deposit, should not be overlooked. These tools should enable mining strategists to better understand the economic levers available to them, and to combat the adverse effects of both price variations and orebody characteristics. A better understanding of the impacts of increasing volumes, and an ability to define the optimal rate of production that an orebody can sustain, has become a pressing need for the industry.

The lesson well learned in the last super-cycle is that capital demands return on investment. While the quantum investment return is fundamental, the efficiency of invested capital or the rate of return is of equal importance. Work done separately by Lane, discussing optimal cut-off grades, and Minnitt, showcasing microeconomic techniques to optimise production rates, leads the way. Ivan Glasenberg, CEO of Glencore, reflecting on the aftermath fallout of the last commodity boom, said that, “Mining companies had erred in chasing growth. It’s really, I believe, catastrophic what we’ve done in this industry. I hope we are in a new paradigm in the mining industry.”[18]

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Chapter 3

Economic Value and Investment Return

“The ultimate test of corporate strategy, the only reliable measure, is whether it creates maximum excess economic value.”

– Alfred Rappaport (1998)

Preview

The new trend sweeping the world today challenges the view that maximising shareholder value as the central aim of corporations leads to greater economic efficiency.[1] This book will not venture into the debate, save to recognise that this debate does not challenge the efficacy of maximising value, but rather the equitable distribution of the wealth within society. These are distinctly two different subject matters. The efficacy of creating shareholders’ value remains unchallenged in generating wealth. To develop and run a mine, significant and patient investment capital must be attracted. To attract capital requires focus on maximising economic value.

Without capital investment, potential economic value cannot be unlocked. In preceding chapters, the neglect of shareholders’ interests and the consequences that ensued, has been described. The mining industry is not new to the debate of wealth distribution and actively recognises the social licence to operate. But the industry also learnt severe lessons of shareholder neglect. Not creating shareholder value has had ruinous consequences for shareholders, for the mining industry and its stakeholders. To neglect their obligations to investors has serious consequences not worth revisiting, and industry stakeholders are well advised to consider that ore deposits have no value without investment. The value of an ore deposit lies in its economic utility, and realising that utility requires significant, patient and risk tolerant capital investment.

At the heart of economics is the recognition that there exist unlimited demands and only limited resources to meet those demands. Consequently, the most efficient approach to mining is one that maximises an ore deposit’s value and trades off alternative opportunities. Investing necessarily implies forgoing an alternative opportunity or what is considered the opportunity cost. The most attractive opportunities are rewarded with capital investment.

KEY CONCEPTS

- Defining Economic Value in Mining
- Critical Considerations
- Measures of Value

I. What Is Economic Value In Mining

“Mineralised bodies are often referred to as valuable resources. In a sense they may be, but regarding them as such can be misleading. They are certainly not a valuable resource that might be compared with cash in a bank or even a crop on the ground. The only immediate value they could possess is the price a mining company might bid for the right to mine them.”[2] That is not the subject matter of this book.This book assumes that an ore deposit has been sufficiently modelled and competently estimated so that a strategic assessment of the viability of the ore deposit can be computed. Attention in this book is given to the “economic value of an ore deposit (as) measured by the dollar value of an asset, calculated according to its ability to produce income in the future.”[3]

Since capital is scarce, the investment maxim holds that the rational investor expects to be compensated based on the risk-reward characteristics of an investment, i.e. the higher the risk, the higher the reward demanded by investors. High-risk and complex mining projects must compete for capital investment and provide an investment incentive to investors opting for the next-best alternative opportunity with alternative risk-reward fundamentals. Economics offers unique perspectives about trading off opportunities in an optimal way to maximise utility. Optimising utility in the investment world is about maximising the value and returns on investment to compensate for the necessary opportunity cost of investment. The alternative investment necessarily foregone is referred to as the opportunity cost of investing. The requirement, therefore, is for miners to demonstrate the capacity of an intended mining project to generate excess profit. Projects generating the highest excess profits are preferentially ranked in the minds of investors and therefore, maximising excess profit continues to differentiate projects that find investment favour.

Excess profit or excess economic value is defined as the additional marginal discounted cash value that one project generates in excess at the required rate of return. Figure 5 illustrates two projects, A and B, to illustrate this idea. Assuming that the required rate of return for investors is 8%, then Project A would be selected, as it returns more excess value than Project B at the selected hurdle rate: Project A: $275 million less $195 million = $80 million Economic value is not an absolute concept, but subject to an investor's risk-reward perception and the measures chosen by the investor to quantify that risk-reward equation. When the expected return is not achieved in time, or the perceived risk of achieving that return changes, the investor will exit the investment, because investment return or risk and uncertainty perceptions elsewhere become relatively more attractive.

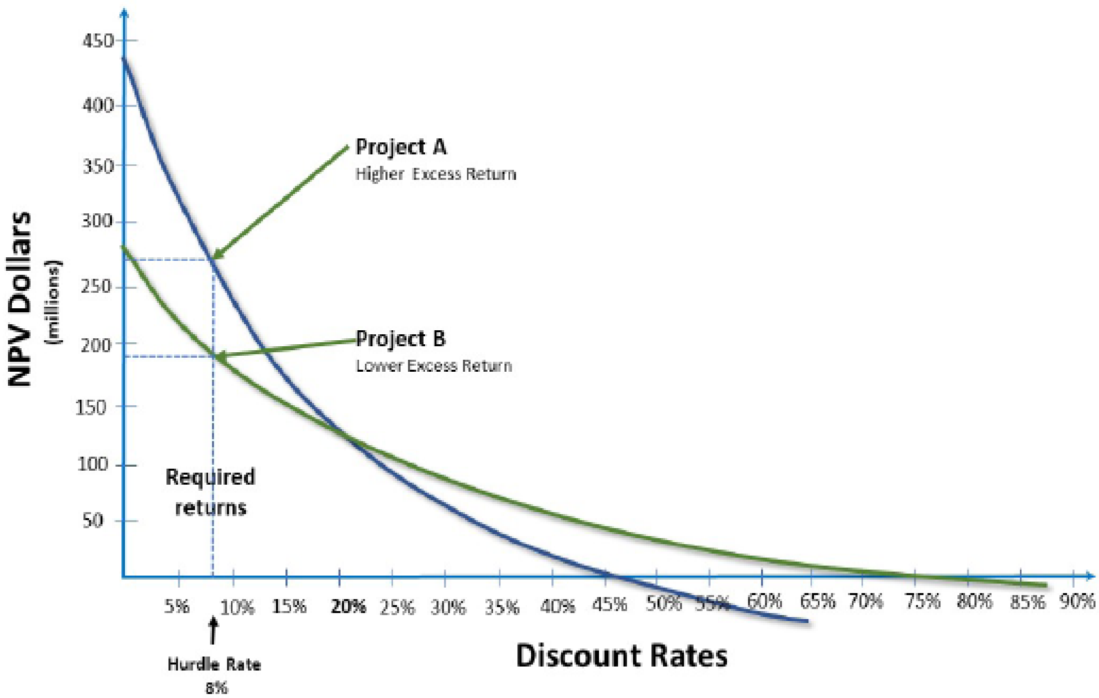

Figure 5: NPV Vs IRR Project Curves

"Every company has limited resources, and (unless the project is small compared to the resources of the company) the decision to proceed will be dependent on the concurrent similar evaluations of alternative projects. In the end, support from a company's board will be forthcoming, only if the funding for a given project fits into a time frame consistent with other demands of the company's resources." Ergo, to attract the required attention and investment, a mining project has to demonstrate excess value that outranks its peers, and to do that, an ore deposit's maximum economic capacity needs to be fully examined.

Mining value is fundamentally dependent upon the nature of the ore deposit and the definition of ore. Each ore deposit is different, and the distribution of mineralisation is peculiar. Mining value requires a fundamental understanding of an ore deposit. "Although exploration personnel often calculate a 'dollar value per ton of rock' to assess targets, in fact, minerals in the ground have no explicit value. Not until they have been extracted, treated, and delivered to a customer is any value realised. Therefore, the economics of ore definition cannot be assessed separately from the economics of the total mining process. Indeed, it is the economics of the mining process which determine the economic definition of ore. Some bases of definition give rise to higher values than others, and therefore the basis which generates the highest value is optimum, and this basis should establish the economic definition of the ore. In other words, material from the mineralised body` should be scheduled for mining as ore if, and only if, the decision to treat it adds to the overall economic maximum value of the operation. This is the crucial criterion."[5]

II. Critical Considerations

Ascribing value to a mining operation is complicated by the degree of geologic uncertainty around reserves and resources, primarily because it is hard to know how much metal is actually in the ground.[6] As such, all assessments of economic viability are only as good as the underlying estimations of contained metals. This introduces the most significant level of uncertainty in assessing the viability of an ore deposit, and this is well recognised by miners. The evolution and development of mining codes over many decades categorises material in terms of geological certainty as illustrated in Figure 6. A further distinction is made between a mineral resource and ore reserves. Ore reserves are considered to be the economic fraction of a mineral resource, after being subjected to understanding the feasibility to develop it. This distinction introduces what Lane refers to, as the whole mining process that requires consideration. In short, assessing mining value is a complex process that requires the condensation of multiple work streams of expert input, and the diligence of each has a bearing on the final assessment of economic viability.

"A strategic assessment (therefore), based on economic criteria, is an important element in a rational decision-making process. This assessment, as well as how well it is understood, is probably the greatest factor differentiating successful projects and successful companies from those that are less successful. The difficulty is that from very early in the evaluation process, some broadly assumed final development scenario defines the path along which all new information and new studies are directed. If information were free and took no time to prepare, all information could be found and a simultaneous comparison of alternatives undertaken. Alternatives that might be equally attractive in economic terms may never get compared."[7] The advances in computing technology and the cohesion of economic concepts and tools outlined in this book make an important contribution to addressing this hurdle.

An important strategic gap currently exists between the conversion of mineral resources to ore reserves, and that being the lack of understanding the viability of multiple alternative options. As Runge (1998) points out, “That if information took no time to prepare and alternatives simultaneously compared, the trajectory for mine development can be optimised.” A strategic assessment must be undertaken early in the evaluation of a project, and it must be as broadly based as possible. The presumption of one or another method will result in path-dependent subsequent decision-making. This path-dependent influence introduces the risk that choices will favour the skills of the participants, rather than (more correctly) being made on the inherent characteristics of the deposit itself.”[8]

The determination of value of an ore deposit is also a time specific metric, because the parameters or forecast drivers vary with time. The most significant driver relates to the changing metal prices and the trajectory of those prices as time passes. Determining a sensible price projection, rather than a forecast or prediction, will be discussed in detail in a later chapter, since its importance in determining future value, after consideration of ore deposit characteristics, heavily influences strategic decisions.

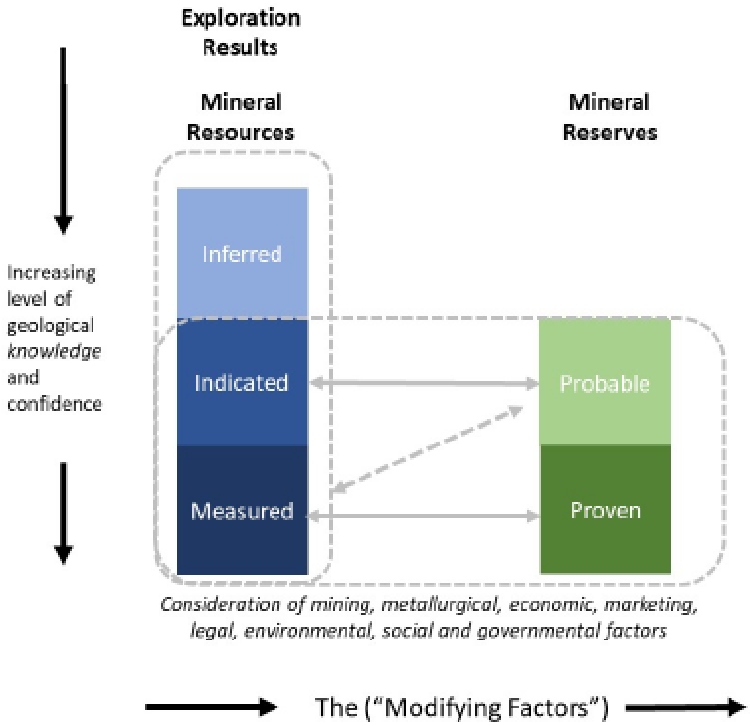

Figure 6: Ore Deposit Classification

Since economic value of an ore deposit can be measured by the dollar value of an asset calculated according to its ability to produce income in the future, all the key parameters defining the varying economic conditions must be included in any present value estimates. These key parameters consider the whole mining process and are well illustrated in Figure 7. The determination of economic ore boundaries, being fundamental to the estimation of value, cannot be divorced from the whole mining equation. Determining the optimal capacity to generate free cash flow and its present value is the only sensible criterion for defining the economic definition of ore and determining an ore deposit's potential economic value.[9] Ergo and as a disciple of Lane, his basic tenant of defining economic boundaries is accepted, and forms the foundation of the author's thinking, together with work undertaken by Minnitt (2007) describing the optimal economic scale of operations that optimises value, by considering microeconomic principle and concepts.

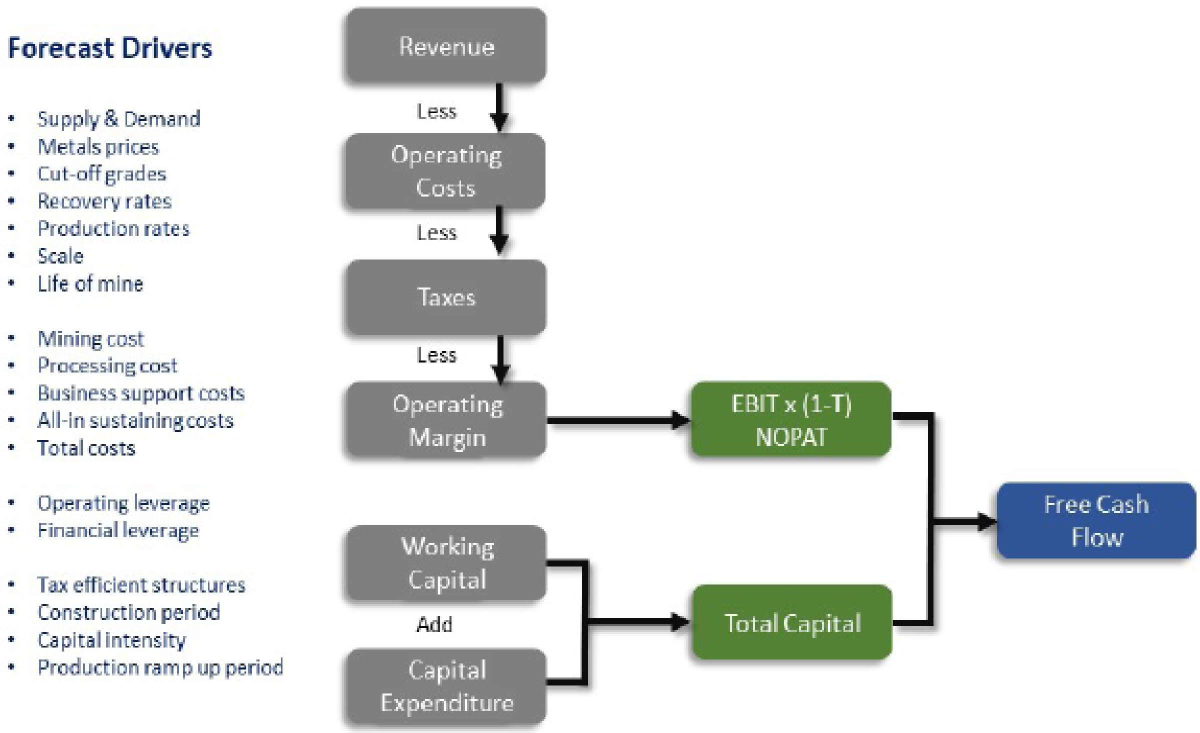

Figure 7: Free Cash Flow Drivers

It is also worth noting Lane's experience when advocating the subject matter of maximising an ore deposit's excess value. He says that because present value maximisation usually indicates higher grades and higher rates of mining, and seems inconsistent with trusted conservative mining policies contributing to scepticism about the present value criterion. he has the following to say: "The two most general contentions are that:

1. Mineralised material should be treated as ore if it will provide a contribution to profit; 2. Mining should be conducted in such a way as to maximise the extraction of valuable mineral."

The cut-off policies which result from the application of these criteria can be the same, depending upon the definition of the terms employed, but they are discussed separately. The first criterion in some form is popular among technical staff. The question of what constitutes a contribution to profit is the subject of much debate, however. It is often argued that any material for which the value of the recovered mineral will exceed the marginal cost of treating it, should be ore. Sometimes a contribution towards overheads is added to the costs and sometimes, beyond this, a minimum profit requirement is also added. The basis of the argument is that if such material is not classified as ore, then an opportunity to earn profit has been wasted. The flaw in the argument is that it totally overlooks capacities. It is equivalent to arguing that a retailer should add to his stock any goods which promise to yield a marginal profit. Retailers do not do this. They are all aware that space is limited, and within this limitation they try to stock the more profitable items. Similar considerations apply to a mine. It has a capacity which is limited by some part of the installation, the shaft, the mill, the truck fleet, the rate of development, etc., and within this limitation it should choose to process the more profitable material. This policy is consistent with the interpretation of the criterion which includes a minimum profit margin, but the supporters of the criterion usually give no basis for determining the margin, other than company policy. The present value criterion, by contrast, gives a precise basis, derived as a trade-off between present and future earnings, via the present value function.

The second criterion that the extraction of valuable mineral should be maximised is frequently proposed by mineral rights owners, local governments and conservationists. Of course, it immediately begs a question, what is valuable mineral? An extreme argument is that all the mineral or all the geological reserves (whatever they are), should be extracted in the interests of conserving resources. This is an unrealistic stance which usually stems from a misunderstanding of the way in which minerals are distributed in the ground. A less extreme view is that the mine should be developed in such a way that poorer material is extracted along with richer material in an acceptable blend, yielding a satisfactory profit. Of course, every mine blends poorer and richer material of necessity, and the point of a cut-off grade is to determine just how poor, poorer material can be. The protagonists of the maximum extraction criterion, however, usually imply a degree of subsidy for poor material, which would not be economical on its own. What this means is unclear, but the idea of cross-subsidies of ore grades is economically unsound, except in special circumstances. A more reasonable view defines valuable material in the same way as in the first criterion. In this case, the two give the same result and suffer from the same objection about the effects of capacity."[10]

Discount rates are commonly used to make accommodation for risk. Higher risk perceptions are accommodated by applying higher discount rates. Understanding the impact of discounting on the cash flow stream should be considered. Beyond twenty years, discounting is disproportionally higher. In Figure 8, the relationship between multiple cash flows and discount rates is illustrated to show the effects of discounting on economic value. Because mining deals with exhaustible resources and a finite life of mines, mining valuations suffer from the exclusion of applying a terminal value in the valuation. Hence, the impact of choosing an appropriate discount rate is no small matter. It is questionable practice as to whether applying higher discount rates to accommodate higher risk perceptions is appropriate. Moreover, given the myriad of varied forecast drivers, it seems that higher discounting is a blunt tool and insufficiently addresses the question of relative uncertainty. With advances in computing technology, there are better ways to assess risk and uncertainty, critical to decision-making. This topic will be dealt with more detail in the next chapter. An important observation that emerges is that discounting dictates that beyond twenty years. Most economic value is heavily discounted, and beyond thirty years any additional marginal value is barely recognised. Large-scale, long-life projects realise the bulk of their value within the twenty-year window, and it challenges the thesis for large-scale, long-life operations, in preference for smaller, shorter life operations yielding greater economic efficiency. The contest will continue, however, as miners are faced with falling mining grades, which are templated to upscale operations in the belief that greater economies of scale are to be had, and which will naturally translate into a higher value proposition. While the thought process is flawed, it must be presumed that ore deposits, largely, are homogenous and that grade variations are constrained. A technique and tool to demonstrate otherwise is sorely sought.

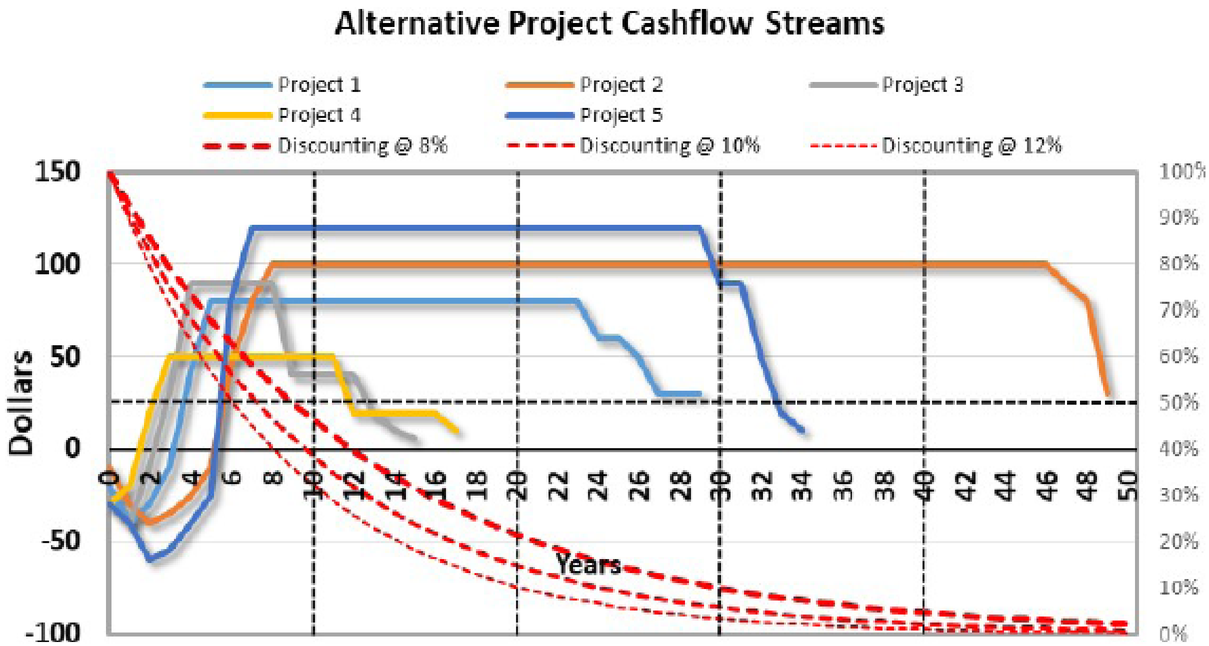

Figure 8: Discounting Rates Versus Multiple Cash Flow Profiles

When discussing an ore deposit's value, it is important to also note that the cost of proving reserves is so high relative to the overall cost of production, that it is more economical to proceed initially without the full extent of economic value being fully defined. Often a business case is made on sufficient reserves to support a value proposition. "Indeed, some of the world's greatest precious metal mines, in production for fifty years or more, have rarely had more than five years of proven reserves."[11]

III. Valuation Metrics

A variety of valuation metrics exist, and include accounting metrics and economic metrics. Mining companies do not rely on only one measure of value to arrive at a decision to commit capital. Runge cautions that accounting metrics can provide misleading and even conflicting signals to decisions based on economic logic. One example he cites is the manner in which depreciation is accounted for. He illustrates this by way of a simplified example that considers the addition of a dozer to an operation. The equated present value yields an expected economic return on assets of 15%. When applying the accounting treatment of this, with respect to depreciation accounting rules, he shows that in the early years the return on assets is lower than the average economic return on assets, and in later years it exceeds the average return on assets. This outcome may cause the accountants to dismantle the tenants, upon which the business case hinges as an operation gets underway in genuine effort to improve the financial fundamentals. Smith et al suggest that, "The ability to develop a continuous feedback loop of business investment performance, relative to original investment criteria (technical, capital, financial and otherwise), is essential if investment decision-making and value maximisation is to be continuously improved. Project Value Tracking (PVT) analysis takes the form of a waterfall chart, which illustrates the relative importance of various external and internal factors that have caused the NPV to change, since the original baseline model makes it possible to compare the present perspective of the project against this original view, on a regular basis."[12] Benchmarking the original accounting measures and embedding a project value tracking tool, as Smith (2006) implemented at Anglo Platinum Plc, is the appropriate way to align the economic metrics and the post project commissioning accounting metrics, to ensure that periodic accounting measures do not derail maximum value harvesting. Smith's project tracking tool will be discussed in more detail in Chapter 9.

To the point, the key economic metrics that are commonly measured and adopted in this book are: ● Net Present Value (NPV)

● Internal Rate of Return (IRR)

● Payback Period (Undiscounted and Discounted) (PBP) ● Cost Benefit Ratio (PVR)

● Capital Investment

● Capital Intensity Factor (CIF):

o Per tonne milled

o Per metal tonne produced

● Life of Mine

● Operating Unit Costs by Tonne Processed and Metal Recovered For any meaningful microeconomic analysis, all these metrics need to be generated and measured. The derivations of these metrics are commonly found in literature, but for the sake of completeness are summarised in Appendix 1.

Nevertheless, investors will determine which metric is the pivotal metric that will be used as the determinant to optimise. For mine design, Lane (2015), suggests that maximising the NPV remains the single most important criterion to consider when defining ore boundaries. McCarthy (2002) points out that if there is no restriction on the available capital, then corporate value is optimised by maximising the Net Present Value (NPV) of every available project and carrying all of them through to production. If capital is limited and capital rationing is required, the Present Value Ratio (PVR) is a useful metric to rank projects. The PVT ratio, being the ratio of PV to initial capital investment, is a measure of the efficiency of every invested dollar, relative to alternative options. If the perceived risks are similar, projects with higher PVRs are selected before those with lower PVRs. A project with a high NPV but a low PVR may require more capital than the corporation (or the investment community) is able or willing to risk, or if developed, it may displace alternatives which are available. Considering the portfolio allocation and metrics chosen to do this, does not diminish from Lane's view that NPV must be the single criterion to optimise the value of an ore deposit, because when applying metrics such as PVR based on optimised NPV, this sets the benchmark for efficient allocation, rather than allocating portfolio flows on underlying estimations of value that are sub-optimal, thereby bringing into question the efficiency of the portfolio allocation.

The adoption of a single metric for portfolio allocation may, however, not be efficient. Figure 9 compares the correlation between PVR, IRR and NPV between the projects described in Figure 8. Using PVR as the metric, the projects would have been ranked: 4, 1, 2, 3, 5 and by using IRR, the projects would be ranked 4, 3, 1, 2, 5. However, on a correlated basis, the ranking would may well be 4, 1, 3, 2, 5, if NPV quantum outranks IRR – the third dimension. There are simply no hard and fast rules for investment strategy, but by maximising the underlying NPV, all other related metrics can be regarded as efficient measures for strategic decision-making.

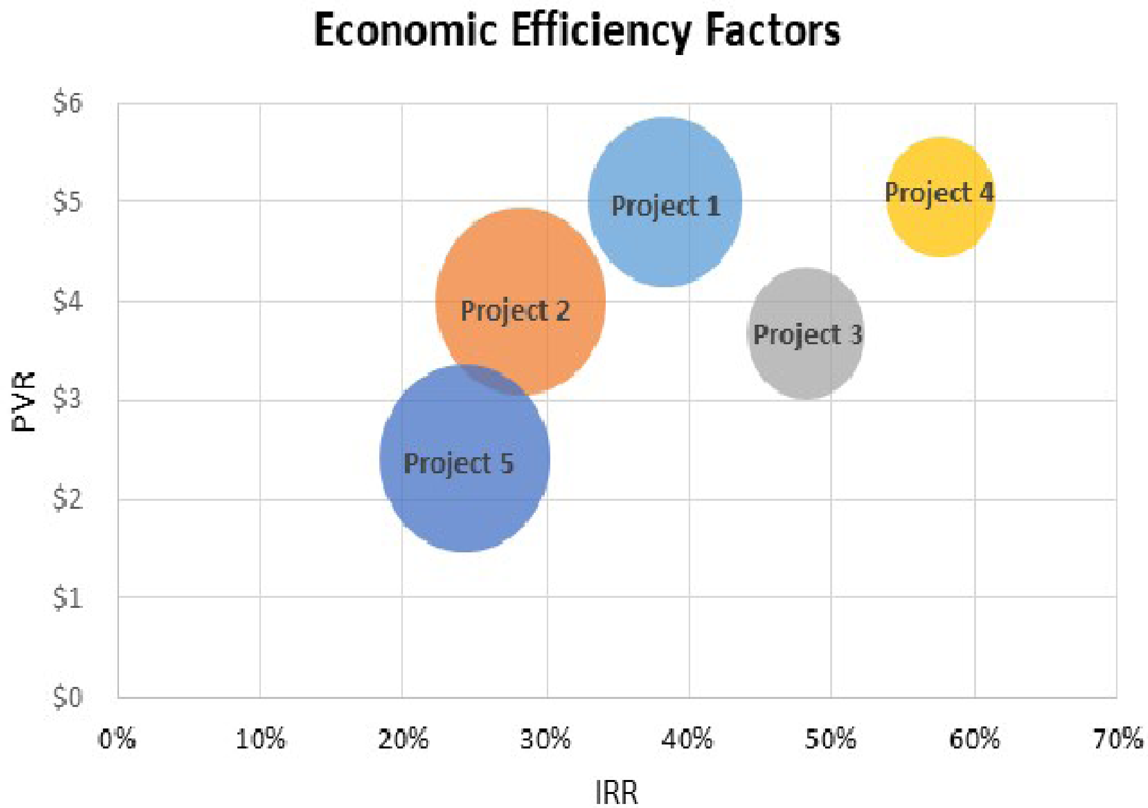

Figure 9: Economic Efficiency Measure

** Balloon size is relative to quantum NPV*

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Chapter 4

Risk and Uncertainty

“Uncertainty is the only certainty there is and knowing how to live with insecurity is the only security.”

– J.A. Paulos

Preview

“The economics of the resources industry is unique, as all mining is subject to uncertainties not applicable to other industries.”[1] It is specifically unique because it relies heavily on estimates of the quality and quantity of the product being produced, rather than tangible determinations. These estimates, in turn, rely on an interpretation of an ore deposit that is fluid through time, as more information is gathered. At the other end of the spectrum, mining investments must consider whether there are volatile macroeconomic conditions, and anticipate implications of supply and demand on price, in the short, medium and long term, and this shapes perceptions of risk and uncertainty.

Both risk and uncertainty have a bearing on investors’ perceptions about the attractiveness of expected investment returns. The investment axiom is that the higher the investment risk, the higher the required investment reward. Mining investment requires large amounts of upfront capital relative to other industries, and that capital is expected to be patient capital. Patient capital must factor in not only technical and financial risks, but uncertainty related to unknown future events. Quantifying the relative risk of mining projects is therefore an important criterion in the investment decision-making process. This can be a complex matter, but an understanding of the breadth and scope of mining risk and uncertainty is the basis for quantifying relative risk, and is an important requirement in any discussion relating to mining investment.

Mining risk and uncertainty is multi-dimensional and mining economics cannot be divorced from uncertainties related to an ore deposit being targeted, or any other key forecast drivers that influence the viability of an ore deposit’s optimal economics. Every mine is different. This chapter will outline key concepts and techniques used to identify and quantify risk and uncertainty from a functional perspective, and as an aid in the decision-making process.

KEY CONCEPTS

- Defining Risk and Uncertainty
- The Scope and Sources of Mining Risk
- Risk Adjusted Decision-Making

I. Uncertainty Vs Risk

“Mining has always fitted uneasily into any standard industry investment models. Each mine deals with unique and wasting assets. Uncertainty is often substantial and frequently unresolvable.[2]” “The risks associated with mining are complex and varied. Depending on their origin, risks may be described as objective, when the risk can be modelled by some mathematical model, or subjective, when personal judgement alters the perceived risk. In addition, the source of risk may be dominated by either potential human intervention or by one’s understanding of largely untested geologically controlled factors, such as interpretive models or structural controls. There are many critical nodes along the mine value chain, from orebody to mineral product, (that) require analysis of the variability and uncertainty of each node, in order to identify and mitigate areas of risk. Decision-makers need to be better informed of the potential risks and opportunities that exist in mining ventures. Communication and compilation of all relevant mining risk sources, and their likelihood and consequence of occurrence, is critical to decision-making.”[3]

Typically, risk practitioners consider risk and uncertainty as very different looking animals, but of the same species, and so the lines of demarcation are often blurred.[4]. “In economics, Knight (1921), is typically credited with the distinction between situations of ‘risk’ and of ‘uncertainty’. In his formulation, ‘risk’ designates situations in which probabilities are known, or knowable in the sense that they can be estimated from past data and calculated, using the laws of probability. By contrast, ‘uncertainty’ refers to situations in which probabilities are neither known, nor can they be deduced, calculated, or estimated in an objective way.”[5]

Knight’s perspective can be summarised as follows:

• Risk is defined as an event in which something of value is forfeited, whilst uncertainty is a condition where there is limited or no knowledge about the future events.

• Risk can be measured and quantified through theoretical models, while uncertainty cannot be modelled or measured as future events are unpredictable.

• The potential outcomes for risk are known and can be quantified, whereas for uncertainty the outcomes are unknown.

• Risk can be managed, whereas uncertainty is beyond the control of an investor or enterprise, as the future is uncertain.

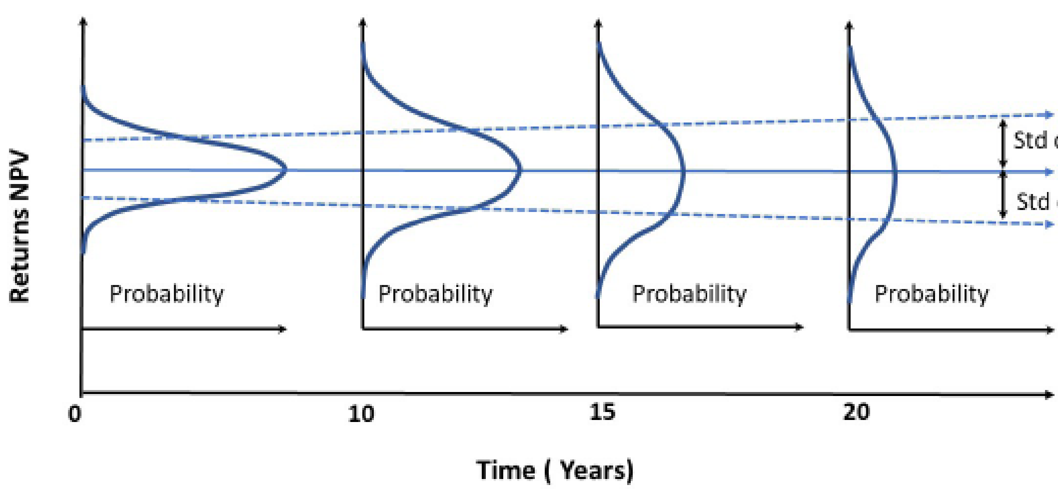
• Risk can be minimised, whilst uncertainty cannot.

• The risk of a set of events can be assigned probabilities, which is not possible in case of uncertainty.[6]

In practice, this distinction is seldom recognised. “The standard practice in economics, when modelling situations of uncertainty, is to follow the Bayesian approach, and to assume that people have probabilistic beliefs over any source of uncertainty, and that they use these probabilistic beliefs in decision-making.”[7] In practice, the term ‘risk’ is used interchangeably with ‘uncertainty’, to refer to the variability of return associated with a given asset.[8] By extension, mining risk must consider the risk and uncertainty of all the underlying variabilities in forecast drivers, objective events and subjective beliefs that ultimately influence NPV calculations.

The relevance of this distinction, however, is that the probabilistic belief of the unmeasurable future has a significant bearing on mining valuation. Bottom line gains are largely controlled by world commodity prices that play a disproportionate influence on cash flows that define investors' expectations of future returns. In Chapter 8, price forecasting and its inaccuracies will be highlighted, because the centrality of metal price forecasts and the rooted uncertainty have a fundamental bearing on probabilistic beliefs and responses to variation in the market-place when outcomes are inconsistent with those beliefs. Recent examples were the slowing GDP of China in 2010, the lack of a timely response by the mining industry, and/or the black swan global financial crisis of 2008.

As a rule, investors' probabilistic beliefs are fashioned to consider, that with the progression of time, uncertainty increases and with that, so does risk Figure 10 depicts probability distributions of returns for one-year, ten-year, and twenty-year forecasts. A band representing ± one standard deviation from the expected return (defined by the apex of the histogram), represents the belief that returns, and therefore risk, increase with the passage of time. Generally, the belief is that the longer-lived an investment, the greater the risk due to increasing variability of returns, resulting in increased forecasting errors for distant years.[9]



Source: Gitman 1994

Figure 10: Time Related Risk And Uncertainty

“It is fair to state, therefore, that risk and risk assessment is as much a psychological state of mind as it is an objective determination. Objective data and subjective beliefs commingle and form the basis of an investor’s perceptions of risk and uncertainty. The resource business is not necessarily minimising risk. Rather it is about managing risk, since minimising or attempting to eliminate it could result in lost opportunities. “There are many assumptions made during mine planning, and the risks associated with some of these assumptions can be high. These risks need to be evaluated and understood as part of the appraisal process, allowing company boards and management to make the correct recommendations and decisions on the future directions of a project, rather than either conservative or ill-informed ones.”[10] The mining industry has begun embracing probability distributions and scenario analysis as a technique to better consider risk and uncertainty. Probability distributions enable risk metrics, such as standard deviation and the Coefficient of Variation (COV), to be calculated and to measure the risk/reward relationship. To enable Bayesian data to be generated, simulation, a statistically-based behavioural approach, applies pre-determined probability distributions and random numbers to estimate risky outcomes and is detailed in Appendix 2. Complementing this, is the growing use of scenarios long used in the oil industry, to enable the development of alternative futures to deal with belief bias and to challenge entrained thought patterns.

II. Risk Analysis and Risk Assessment

Traditionally, mine planning has a less than enviable track record of estimating value, despite all the engineering effort and energy expended. “Bankable” and/or “definitive” feasibility studies have been, and can be misleading. The term “bankable” is misleading as the return outcomes remain subject to uncertainty, ergo the certainty imputed to “bankable” does not exist, save for a high degree of engineering precision. Greater precision does not eliminate uncertainty or improve the accuracy of outcomes, it just means that engineers can be precisely wrong. To be useful, decision-makers need to be better informed of the potential risks and opportunities that exist in mining ventures. At the feasibility stage of a project, the range of most likely scenarios, including upside and downside cases, all need to be tested to determine their effect on economic decision-making. Communication and compilation of all relevant mining risk sources, and their likelihood and consequence of occurrence, is critical to decision-making. Interdisciplinary input, involving complex analysis, is required to determine the value adding opportunity at each node, in order to optimise the overall mine process. The value chain must be optimised from the beginning to the end of this process, in order to identify those high-risk areas and mitigate their impact, thus maximising mine dollar value. Interdisciplinary components, including geology, geomechanical, and mining and metallurgical engineering, are closely linked at each stage from exploration, through feasibility studies, to grade control, mining, processing, and marketing.[11]

Figure 11 illustrates the sources of mining risk and uncertainty that need to also be considered in a risk matrix.

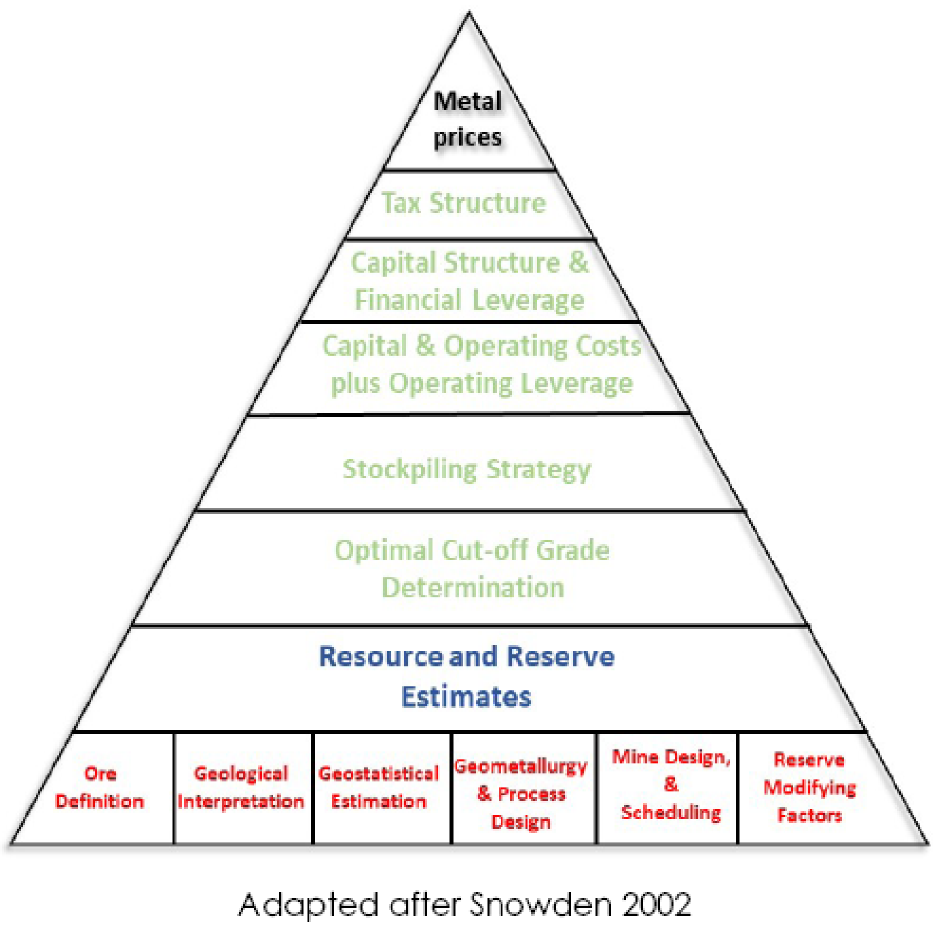


Figure 11: Scope and Sources of Mining Risks

Sensitivity Analysis

Sensitivity analysis illustrated in Figure 12 is widely used in the mining industry to assess the impact of errors in grade, metal price, metallurgical recovery, production rates and costs on project value or NPV. Sensitivity analysis is simply the process of examining the impact of errors by assuming that one variable is changed at a time, independently of other variables, and measuring the corresponding impact on value. It is relied upon because it is simplistic and easily crafted. Fundamentally, it suffers the weakness in that a single variable seldom if ever changes singularly and it says little of the probability of that change. Moreover, and typically, only a limited number of forecast drivers are considered, and it ignores more fundamental drivers related to the ore deposit. Sensitivity analysis only considers how far a variable needs to change, but disregards simultaneous changes in either variables. For example, when production rates increase, there is generally a corresponding reduction in grades. Thus, any static benefit perceived from increased production is not imputed to a reduction in revenue. Another example is that if there is a reduction in scaled volume, a corresponding reduction in capital expenditure, and possibly a rise in operating costs, should occur. It is therefore evident, that while the information value of sensitivity analysis has some use, its informational value alone is limited.

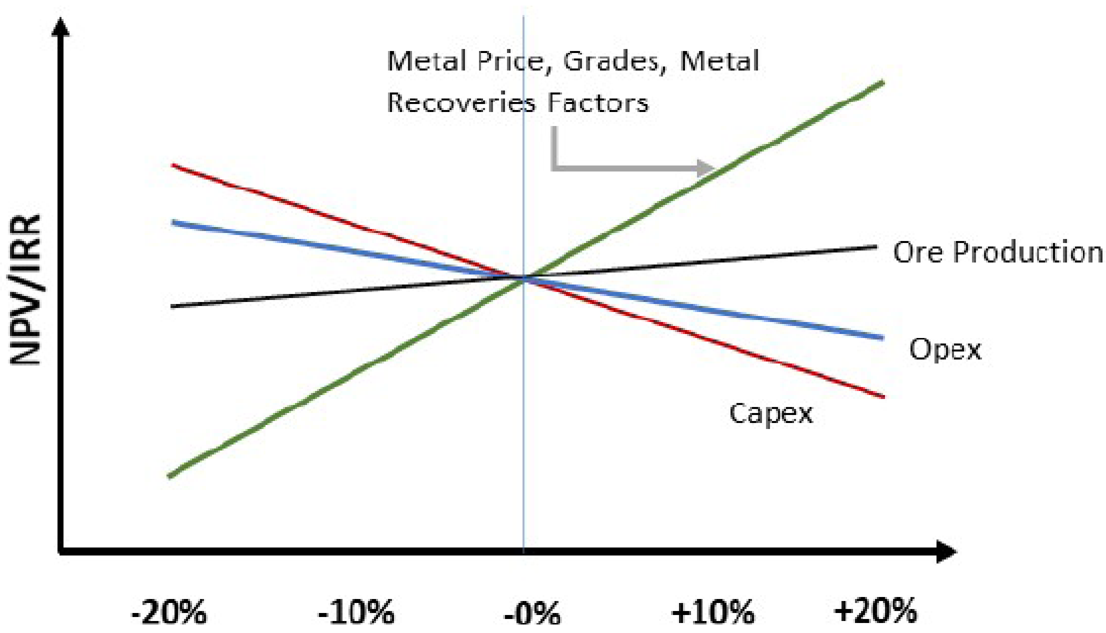


Figure 12: Sensitivity Graph

Risk Matrix

The risk matrix is commonly used to identify and assess technical risk in mining ventures shown in Figure 13. It improves upon the information value of the sensitivity graph, by identifying underlying risk, its likelihood of occurrence and its severity. It is a great leap ahead of sensitivity analysis, as it identifies a greater array of risks and consequence. Its greatest weakness, however, is that it is disconnected to financial analysis and is largely qualitative, rather than quantitative. Too often, this risk assessment is merely undertaken as a tick box, and then ignored once a mine is commissioned. Notwithstanding, it tends to focus attention on high impact risks, rather than the accumulative effect of multiple low impact events, that often collectively equate to a single high impact event. The information greatly improves on the sensitivity analysis, but due to the disconnect to cash flow, modelling its value is often underutilised.

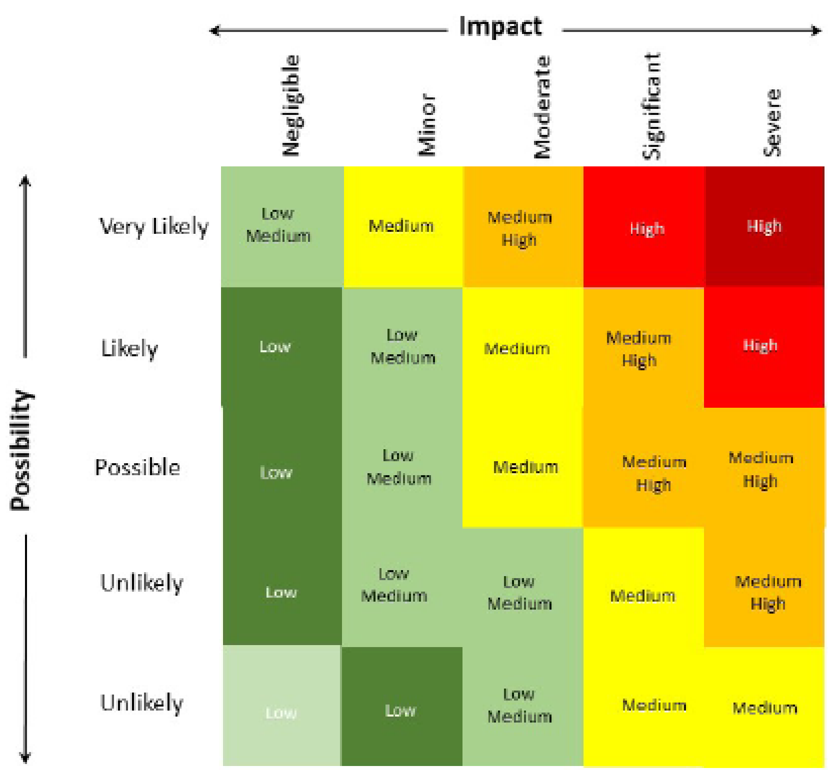


Figure 13: Risk Matrix

Risk Adjusted Discount Rates

To compensate for this, heavy reliance is put on risk adjusted discount rates (RADR) to account for mining risk in financial modelling. A risk-adjusted discount rate is the rate obtained by combining an expected risk premium, with the risk-free rate during the calculation of the present value of a risky investment. The hypothesis for RADR is that by increasing the discount rate and lowering the NPV, risk and uncertainty can be adequately accounted for. This is an over-simplification of the myriad of risks and the probability, and fundamentally ignores the potential upside that a project can deliver. It is fundamentally flawed for two reasons; it assumes that a marginal increase in discount rates can capture a significant reach of mining risk, and then implies that these risks remain constant for the life of the mine. It is worth noting that superficially similar mines have [often] turned in vastly different profit performances. Management decision-making has a greater influence on industry profitability than has been acknowledged, and there are many examples of rich orebodies not producing profitable mines and mediocre orebodies turning into successful long-term enterprises. As Rozman (1998), points out, "The resource business is about managing risk, not necessarily minimising risk, since this could result in lost opportunities. For example, he describes that if the upside at Sunrise Dam in Western Australia had not been recognised, it may never have been mined. In 1998 it had produced 60% more gold than originally estimated."[12]

Risk analysis and risk assessment, to be meaningful, should be "expressed as a level of confidence, which considers the scale or period over which the risk is being assessed (life-of-mine, annual or shorter production periods) and should convey the likelihood, severity and consequence of occurrence of a given event. The future generation of mining specialists needs to understand the entire mine value chain, to better manage risks and maximise mine dollar-value."[13] To underestimate the importance of the information value of comprehensive risk analysis, is to risk the performance of invested capital.

III. Quantifying Uncertainty

In its simplest definition, a probability distribution is a model that relates probabilities to the associated outcomes. Probability distributions can provide an objective means to capture both objective and subjective variability in the forecast drivers that influence expected returns. "The simplest type of probability distribution is the bar chart, which shows only a limited number of outcomes of probability coordinates."[14] The simplest form of a probability distribution is a bar chart showing a limited number of probability-coordinates shown in Figure 14. below. By comparison, the bar charts reflect a range of dispersion or deviation, applying probabilities to the alternative potential returns, so the expected return can be calculated. For example, Project 1's expected return is $500, while that of Project 4 is $239, being the weighted average of alternative NPV, weighted by assigned probabilities. The standard deviation of Project 1 is computed at $318, while for Project 4, the standard deviation is $89. In this example, the standard deviation suggests that Project 1 deviation suggests that Project 1 is more risk than Project 4, and therefore on a risk/reward efficiency basis, Project 4 should be considered ahead of Project 1. The expected value is not a single computed value but the result of the weighted average of a probability factor and multiplied by the corresponding return value. More formally, the equation is expressed as:

$$\bar{k} = \sum_{i=1}^{n} k_i x \, \rho r_i$$

Where:

ki	=	return of the *ith* outcome
pri	=	probability of occurrence of the *ith* outcome
n	=	number of outcomes considered

Other outcomes are dispersed around this value. The degree of dispersion and the common statistical measure for assessing risk arethe standard deviations. The mathematical expression for this is:

$$\sigma_k = \sqrt{\sum_{i=1}^{n}(k_i - \bar{k})^2 \times \rho r_i'}$$

Where:

ki	=	*return of the ith outcome*
pri	=	*probability of occurrence of the ith outcome*
n	=	*number of outcomes considered*

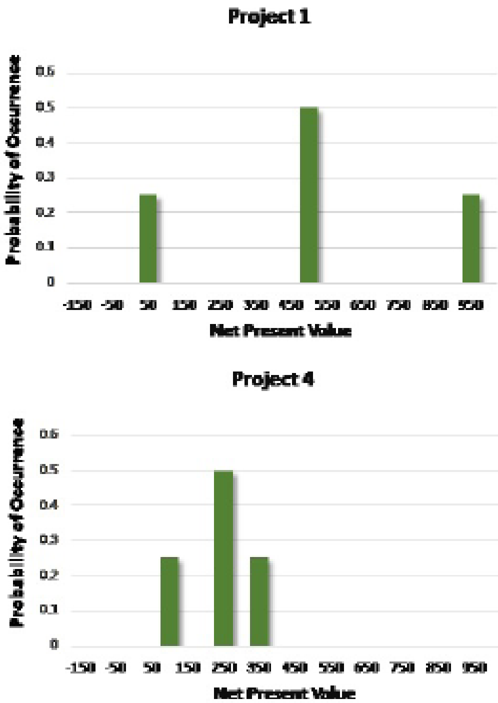
A circumstance may arise where the range and standard deviation for Project 1 is lower, but still larger in quantum than Project 4. Since the standard deviation remains higher than Project 4, the decision criteria remain unchanged. However, to consistently compare projects of varying quantums, the coefficient of variation (COV) is used, since it provides a relative standardised measure of dispersion around the expected value.

The COV is expressed mathematically as:

$$CV = \frac{\sigma_k}{\bar{k}}$$

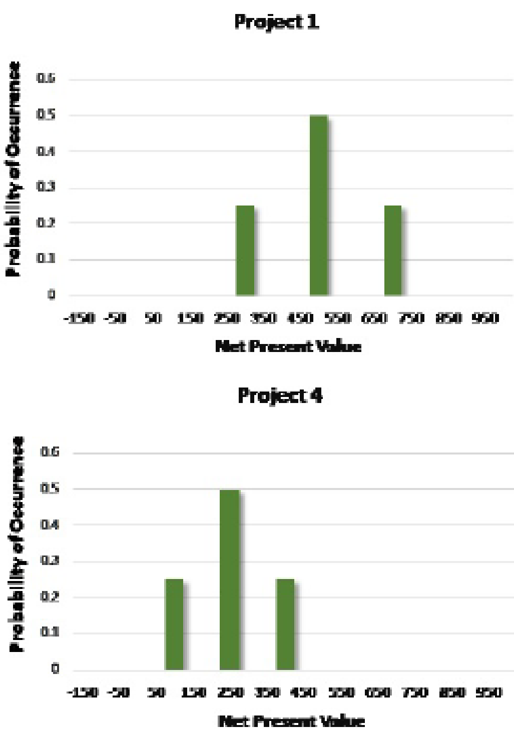
Where:

Σ	=	*standard deviation*
	=	*expected return*



	Project 1	Project 4
Initial Investment	**-100**	**-50**
NPV Returns		
Under perform	$50	$100
Base case	$500	$253
Over perform	$950	$350
Range	($900)	($250)
Probabilities	100%	100%
Under perform	25%	25%
Base case	50%	50%
Over perform	25%	25%
Expected Returns	$500	$239
Standard Deviation	$318	$89
Coefficient of Deviation	0.64	0.37

Figure 14: Probability Curves, Expected Returns, Standard Deviations



	Project 1	Project 4
Initial Investment	**-100**	**-50**
NPV Returns		
Under perform	$300	$100
Base case	$500	$253
Over perform	$700	$350
Range	($400)	($250)
Probabilities	100%	100%
Under perform	25%	25%
Base case	50%	50%
Over perform	25%	25%
Expected Returns	$500	$239
Standard Deviation	$141	$89
Coefficient of Deviation	0.28	0.37

Figure 15: Probability Curves, Expected Returns, Standard Deviations and Coefficient of Variation

In Figure 15 and on the basis that alternative returns were determined, it appears that the decision based on the deviation remains intact. Standardising the metrics by means of applying the COV of Project 1 to Project 4, suggests that on a relative basis, Project 1 should be favoured above Project 4, as the relative risk is lower. The COV in this example is 0.28 for Project 1, compared to a COV of 0.37 for Project 4. Ergo, as a standard, COV proves to be a more reliable metric to measure relative risk as a consistent measure with projects of varying return quantums and deviation around the expected means.

Probability distributions that are continuous provide greater informational value than non-continuous distributions. In the above examples, the probability of loss is unclear. The continuous probability curve described in Figure 16 shows the probabilities that exist at zero and beyond. Continuous probability curves provide a wider range of probability outcomes, allowing for the single point deterministic value to be plotted relative to the expected returns and position—relative to expected probability of loss. This perspective of dispersion is rather useful, as it also defines that the probability of Value as Risk for any given scenario may highlight whether the deterministic assumptions are either optimistic and/or pessimistic. It can also provide insights, as to which forecast drivers can be adjusted to cushion the effects of adverse movement in metal prices, for e.g. adjusting cut-off grades.

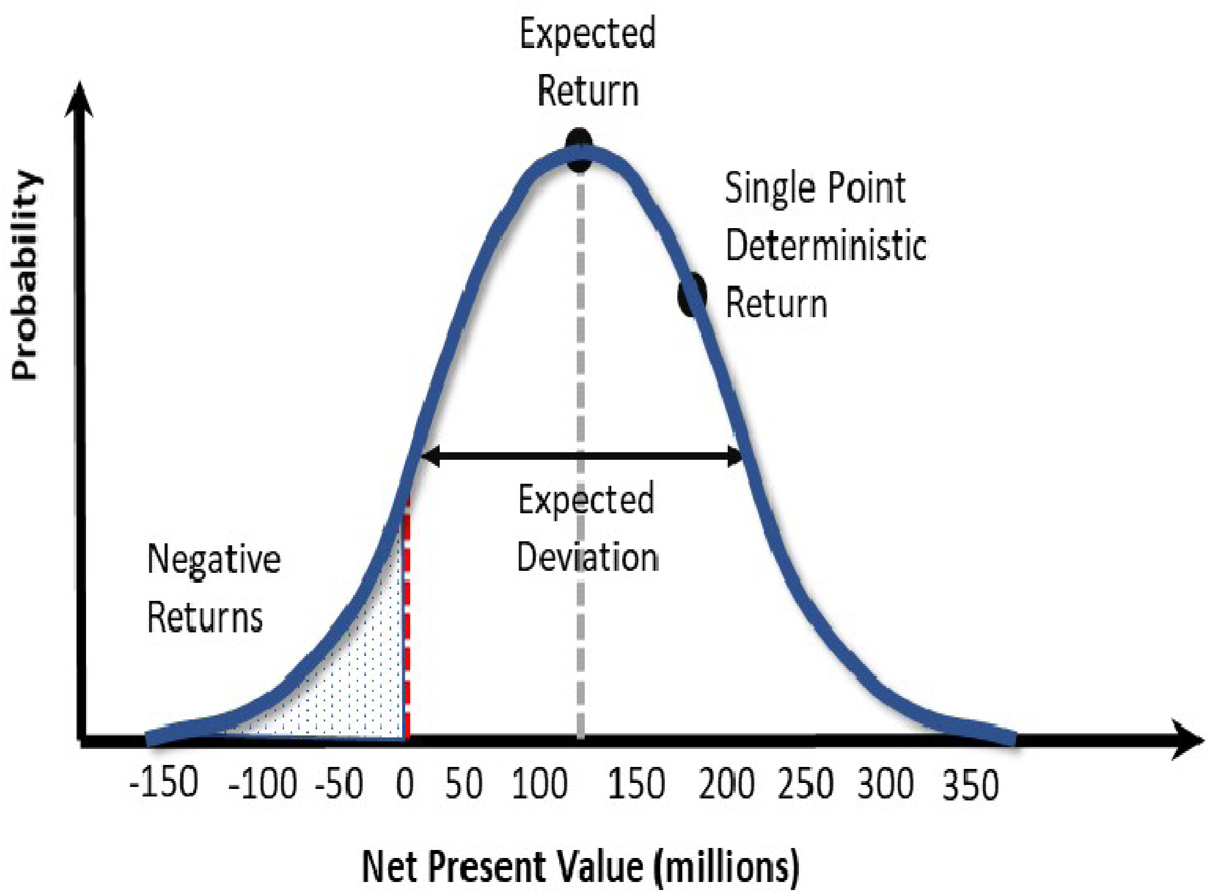


Figure 16: Continuous Probability Distribution

Monte Carlo Simulation

The Monte Carlo Simulation (MCS) is a statistical technique used to model components (variables) of project cash flow, which are impacted by uncertainty. It is a tool used for developing a model of uncertainty, which can incorporate risk profiles for decision-making. It has been widely used in the petroleum industry since the late 1960s, for understanding decision alternatives. It allows risk and uncertainty to be described as a range and distribution of possible values for each unknown factor, rather than a single, discrete average. "The purpose of a simulation analysis is to be able to account for potential variability in profitability. This technique is equally useful for the mining industry and has been applied to assessing financial models, as well as technical options in mining engineering," [15] while investors grasp the probability that expected NPV will be greater than a zero return or loss on investment.

Whilst MCS has considerable advantages, its strength or weakness lies in the skill, knowledge and experience in designing the underlying model that it affords to correctly measure the key variables that affect cash flow generation. Often in mining project valuation, MCS seldom has a direct link back to the ore deposit being exploited. Considering that the orebody is the key to generating value, the exclusion of the orebody from the MCS is more than a benign oversight. Moreover, the impact of changing economic inputs on the microeconomic and technical parameters of an asset, is not linear, and therefore, the expected value of an ore deposit will fluctuate with time as they directly affect more than one of the following at a time:

● The size of the mining inventory as a function of the cut-off grade of an ore deposit and leading to higher or lower mining grade of the deposit;

● The effective economic life of the mining project;

● Attributable costs associated with exploitation; and

● Free cash flows.

Figure 17 presents a flowchart of a simulation of the NPV of a project. By tying various forecast drivers within a mathematical model, and varying the forecast drivers numerous times, a probability distribution can be generated. The process of generating random numbers is relatively easy with modern software, but to be effective and credible, MCS needs to be conducted by experienced and knowledgeable practitioners, who fully understand the mining value chain and who have a considerable grasp of mining economics, which includes an intimate understanding of the ore deposit and how the scale of operations affects all other variables in the mining value chain.

Today, modern computing power allows for complex and sophisticated models to be designed to this purpose, and the ability to interrogate the underlying probability ranges driving an MCS simulation. MCS alone, however, is not the panacea for quantifying risk and uncertainty.

Understanding that risk and uncertainty are different, requires consideration for assessing alternative future realities. This is best undertaken by considering the future in the context of alternative future scenarios.

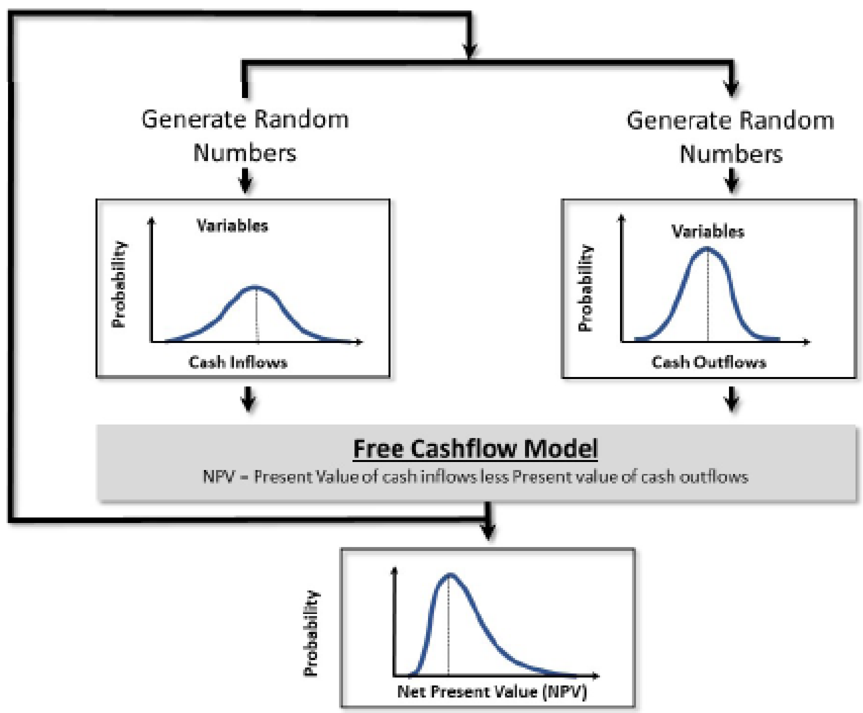


Figure 17: Monte Carlo Simulation Illustrated

Scenario Analysis

Uncertainty today is not just an occasional, temporary deviation from a reasonable predictability. It is a basic structural feature of the business environment, and therefore scenario analysis is a method used to think about and plan for the future, appropriate to a changed business environment. Forecasts are usually constructed on the assumption that tomorrow's world will be much like today's, and this makes them so dangerous. Often they work, because the world does not always change. But sooner or later, forecasts will fail when they are needed most in anticipating major shifts in the business environment that make whole strategies obsolete.

The weakness of simply doing single MCS is that it represents a value for a given set of economic criteria at a point in time. Whilst this has enormous value, it represents only a first order level of uncertainty. Mine depletion timelines vary greatly, from a few years to decades. Large corporate mining companies have to consider the impacts of sustaining their project portfolios and reassess strategic focus as forecast drivers change over time.

For example, surprise.

To address this, is not to try to perfect forecasts by increasing mathematical complexity. Rather it is to accept uncertainty as indeterminable, and then to craft possible alternatives to the current beliefs of the future. Understanding the alternative outcomes to current beliefs on future value, has significant value, as it allows management teams an opportunity to properly craft strategy and tactics to address the constantly changing set of environmental dynamics that encompass economics, politics, environment, and legal and social pressures.

Beginning in the late 1960s and early 1970s, Shell developed a technique known as “scenario planning”. By listening to planners’ analysis of the global business environment, Shell’s management was prepared for the eventuality, if not the timing, of the 1973 oil crisis. And again in 1981, when other oil companies stockpiled reserves in the aftermath of the outbreak of the Iran-Iraq war, Shell sold off its excess before the glut became a reality and prices collapsed.

Scenarios “do not predict the future, but describe a set of plausible and challenging future landscapes. Scenarios are not about what will or should happen, but about what could happen. Who needs a time machine when you can travel so smartly to alternate futures?”[16]

Most scenarios just quantify alternative outcomes of obvious uncertainties, (for example, the copper price may range between $/tonne 5500 and $/tonne 6500). Such scenarios are not helpful for long-term strategic thinking. Such scenarios can be considered “first-generation”, and offer little in the way the world is headed and the appropriate strategic response. Shell’s decision scenarios are quite different, as they are designed to challenge the mental model of reality of the company’s decision-makers and the rank and file. Whilst a detailed discussion on scenario analysis is beyond the scope of this book, it is worthwhile to outline an approach to scenario analysis, in order to consider how uncertainty can be addressed and to roadmap a strategic and tactical response.

Iv. A Strategic Framework

Without a strategic framework, risk and uncertainty is undertaken in a disconnected and inconsistent manner. The strategic planning process takes cognizance of a changing world, while recognising the inherent uncertainties. The strategic planning process aims to develop schemes that have a greater adaptability and hence higher chance of achieving expectations in the face of change.

Strategic planning and strategy development is a key phase in the development of any mining project. “Critical decisions are made concerning mine development strategy, with respect to the scale of the operation and the maximisation of profitability. Alternative strategy options have significant differences in project economics, as strategic direction has major influences on costs, risks and the capacity to accommodate change.[17]

A strategic framework provides a consistent approach and provides a communication tool to mine planners and mine managers, to ensure strategic alignment by imposing a consistent rigour of approach. The rigour begins with understanding the economics of an ore deposit, and fully understanding what each ore deposit can sustain in terms of scale, mining method, processing options and costs to maximise investment returns. Understanding the “Hill of Value”, and identifying the hurdles and barriers to achieving maximum value, while defining the risks and uncertainties, is a critical task of strategic planning. The implications and uncertainties provide the basis for rational strategic choice.

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Chapter 5

Mining Economics and Strategy

“The balancing act between desirability, feasibility and viability separates winners from losers”

– INDP Center, Inc

Preview

“The rigours of international competition have caused mining companies the world over to re-examine the way their organisations are run, and the key performance indicators they use in judging success. In a dynamic and fast changing world, the luxury of trial and error is not available.”[1] Strategic management is not about crystal ball gazing or peering into the future. Rather, strategic management defines a roadmap, by outlining where the business is going to compete, the resources it will require to do so, how to differentiate it from competitors, identify what organisational levers it will deploy to enhance its performance, and importantly where and how money will be made.[2]

The key to staying ahead of competitors and to differentiate from them, is to constantly challenge entrenched beliefs and ways of doing things. Adopting new mindsets and new ways of thinking lies at the heart of innovation and strategic management. This chapter considers the strategic planning process, and introduces design theory, so successfully used in other industries.

Strategic planning is “essentially the link between the enterprise business strategy, informed by market requirements, and tactical planning activities. Strategic long-term planning creates the basis for the development of a portfolio of operations, both current and future, that ensures optimal resource exploitation, while creating the flexibility to respond to changing economic and market conditions.”[3]

The question of choice arises because the basic resources such as capital, land, labour and management are limited and can be put to alternative uses. The decision-making function thus becomes one of making choices and taking decisions that will provide the most efficient means of attaining a desired end. It would be in the interest of the business to reach an optimal decision, i.e. the one that promotes the goal of the business firm.”[4]

KEY CONCEPTS

- Strategic Thinking
- Design Theory
- Preliminary Economic Assessments
- Technical Framework to an Economic Framework

I. Strategic Thinking

"A strategic assessment, based on economic criteria, is an important element in a rational decision-making process. This assessment, and how well it is understood, is probably the greatest factor differentiating successful projects and successful companies from those that are less successful." It follows that mine design and planning is an integral part of strategic thinking and planning. Too often, mine planning and strategic thinking are weakly connected and largely disconnected from the economics of the ore deposit being exploited. The status quo is to passively rely on mine planners to inform the C-suite of the feasibility of mining a particular deposit. Often little direction is given to these mine planners, in terms of key metrics that are needed to be achieved beyond an IRR hurdle rate and/or a discount rate, to apply for discounting cash flows. The prevailing assumption in the past was to maximise the duration of mining operations and to achieve a cost structure below the 50 percentile on the industry cost curve. Beyond that, mine designers were largely left in the dark, save that the resolution of technical issues was often seen as the primary focus of a feasibility study, whereas in reality, these technical issues are only the basis upon which an asset delivery and business plan is built."[6] Thinking that has little changed.

Declining grades and more complex mineralogies are two of the major business challenges that miners face globally today. The default response is to prioritise mining rates to achieve economies of scale in an effort to realise lower unit costs of production. This thinking presupposes that mining is a simplistic linear equation and that simply applying such logic will obviously result in the linear solution. The mining business is all about the ore deposit, and the mining equation is an intricately interconnected non-linear system; and applying rigid linear thinking results in disconnected sub-optimal outcomes. One example, "it should be borne in mind that lowering the cut-off grade of ores:

- Increases asymptotically the quantity of ore to be excavated and treated;

- Increases energy and chemical usage;
- generates larger volumes of tailings to be managed; and
- often decreases profitability."[7]

The solution also does not lie in greater technical rigour or technical ingenuity, as is often touted, but in having a more fundamental and better comprehension of an ore deposit's economic capacity and therefore viability, early on. The essence of this book is to showcase how that can be achieved in an effective, comprehensive and timely manner.

Due to the complexities of the mining value chain, the vast inherent uncertainties that underpin the mining equation, and notwithstanding a business environment that is continually changing, it follows that maximising the utilisation from any ore deposit cannot be divorced from strategic thinking. Over time, mining companies have developed strategic management processes as the platform to drive and guide the development of their project pipeline. Some elements of the strategic planning processes that have evolved are indeed ingenious, but sadly the primacy of the ore deposit is often neglected, despite objections to the contrary. This book does not suggest a radical divergence from proven and tested approaches that have evolved over time, but rather, augmenting them with new insights that have evolved in other industries. This book, though, affirms the primacy of the ore deposit to steer strategic thinking and project development and refocuses the emphasis away from a purely technical bias in decision-making, towards a strong economic bias that is informed by an ore deposit's capacity to support optimal economic outcomes. Ergo, this chapter's emphasis is not to focus on the most economical way of mining, but to reconsider the most effective manner of strategically assessing mining projects. The challenge is not to simply rethink mining strategy, but to rethink how we craft mining strategy, while taking equal notice of the forces of world progress and the forces governing individual human action.[8]

The concepts of viability and feasibility are used interchangeably in the mining industry, and this is not surprising, as the two concepts are also used interchangeably elsewhere and in other industries. The popularisation of Design Thinking by John E. Arnold, Professor of Mechanical Engineering at Stanford University in 1959, in his work entitled “Creative Engineering”, gave rise to a thinking process to solve complex problems that gives rise to practical results and solutions.[9] Design Thinking focused attention on technical feasibility, economic viability, and user desirability. The ideology behind this approach is to drive innovative solutions to complex problems, within the constraints of limited resources.

The distinction between feasibility and viability is therefore made in Design Thinking. Viability is more explicitly defined as the exploration of the profitability possibilities and justification of investments of a business, whereas feasibility questions whether the business or project being considered can be realistically realised, given the time and resources made available. The third focus places attention on desirability. Designing tools or solutions that are desirable focuses attention on the satisfaction of human need. In mining, the attention is focused on the desirability of commodities required to make products that the world requires. In the 21st century, the drive for a green economy is driving miners to prioritise attention away from the carbon economy, towards commodities that will support the green economy. Design Thinking is readily compatible with the mining industry’s proven and tested strategic frameworks, but offers a fresh new mindset to tackling the increasing complexities that miners are faced with.

The Double Diamond Diagram was developed by the British Design Council in 2005, as part of its in-house research to identify how leading companies manage the design process. The framework considers four main stages; Discover, Define, Develop and Deliver. The first two stages define the project strategy, while the third and fourth represent the executive solution[10]. The basic framework is illustrated in Figure 18 and has a direct linkage to the mining value chain. This chapter will consider the adoption of Design

Thinking and processes in the strategic planning process, to enhance the strategic thought process for developing mining strategy.

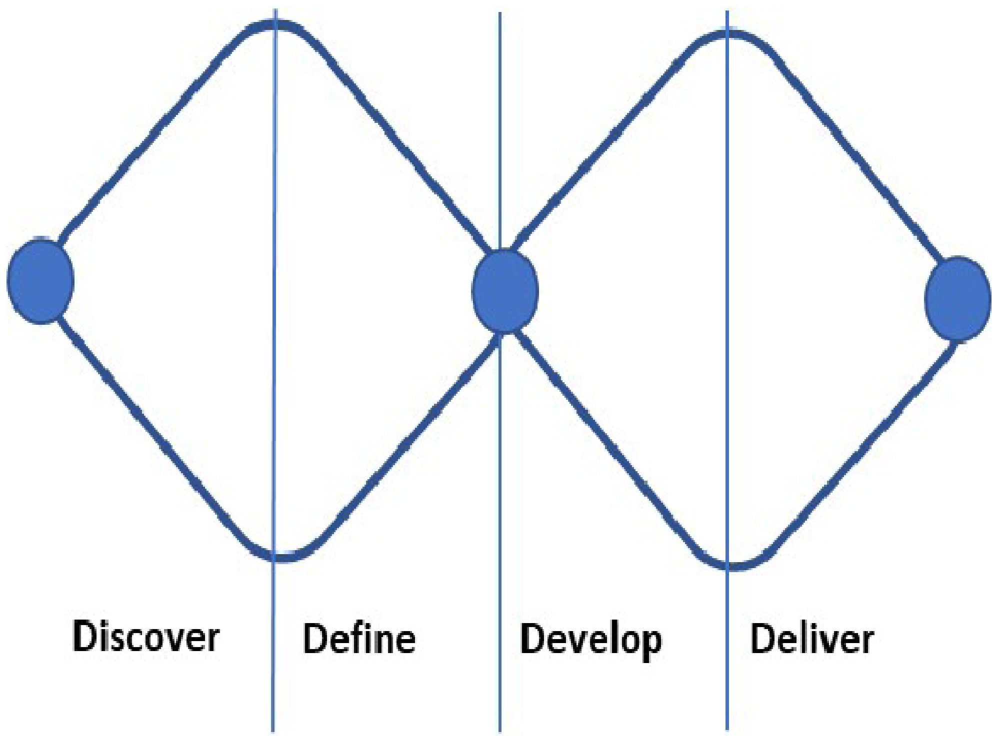

Figure 18: Design Thinking: the Double Diamond Diagram

MINING VALUE CHAIN

Before outlining the Design Thinking approach, it is useful to describe the mine value chain, to show how readily it can be applied in the mining industry. The range of disciplines and activities required to establish a mine are illustrated in Figure 19. The mining value chain is a complex of interrelated activities that include disciplines such as geology, geochemistry, geophysics, geostatistics, mining, metallurgical, chemical, civil, electrical, mechanical engineering and environmental, notwithstanding legal, political, community and economic disciplines (amongst others) that, combined, progress a mining discovery into an operating mine.

Goldfield Minerals Services (GFMS) has previously defined the mining value chain process as a set of sequential steps, namely: discover, define, design, develop, deplete and decommission. These steps are not inconsistent with Design Thinking, as the first four D's match Design Thinking practice. The content of these steps is neatly outlined in the Goldfields Mining Company Ltd 2016 annual report, Figure 19. Discovery requires generative exploration activities listed, whilst Defining requires activities that are aimed at defining a Mineral Resource. Design relates to all planning activities that are ultimately required to maximise Free Cash Flows from future operations. Development of a mine can be lengthy and complex, and culminates in rocks being processed and metals production.

The Mining Value Chain

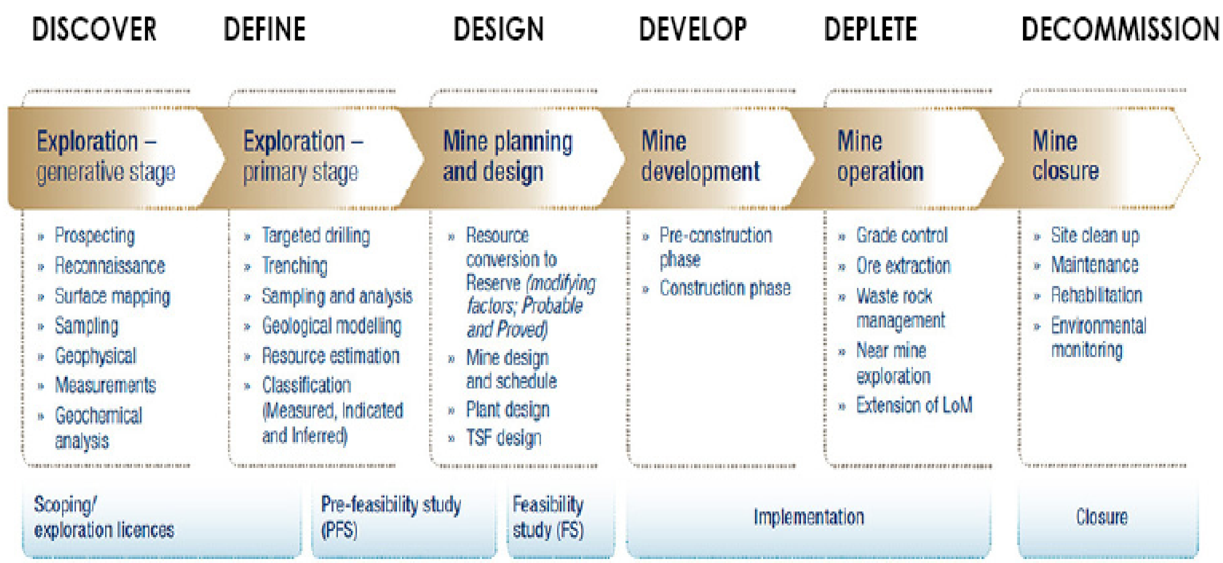

Figure 19: Mining Value Chain

Depletion refers to the mining process and the management thereof, to ensure that the designed mine delivers the expected outcomes. Mining is in the business of utilising depleting exhaustible assets, and every pit or underground operation has a finite life. When this finite life is reached, the mine has to be decommissioned. In today's world, miners cannot lawfully dig holes and walk away once the deposit is exhausted. Attention has to be given to restoring the mine site and ensuring that no harm is caused as a result of abandonment.

Usefully, the illustration describes the study path in the first four phases, these phases being identical to Design Thinking phases. Miners have, over time, developed a sequential set of studies in order to motivate investment to the next stage gate. "Typically, initial assessments of the development potential of a resource project, are aimed at assessing the project's key technical and economic characteristics, with subsequent assessments designed to confirm assumptions and reduce the uncertainty associated with the development to an acceptable level. References to feasibility studies are often prefaced with 'order of magnitude', 'preliminary', 'indicative', 'pre', 'final', 'bankable', 'definitive', 'detailed' or other terms to indicate the level of detail investigated in a study. Despite this feasibility, studies are notoriously unreliable ex post, despite "regularly portrayed as being much more comprehensive and accurate than they are."[11] Regrettably, engineering precision in these studies is often mistaken for accuracy of forecasted project returns. The concept that engineering studies produce results in "bankable" outcomes is common, but misleading. Engineering design and detail cannot compensate for the inherent uncertainties of the ore deposit and/or the dynamics of the market, and hence engineering confidence levels for each study are of a narrow stroke. The final study should dispense with being labelled bankable or definitive in favour of the term Detailed, since even these detailed studies are subject to significant uncertainties beyond the scope of engineering excellence.

II. Reliability of Feasibility Studies

The goal of a feasibility study is stated as:

To assesses in detail the technical soundness and economic viability of a mining project and serves as the basis for the investment decision and as a bankable document for project financing. The study constitutes an audit of all geological, engineering, environmental, legal and economic information, accumulated on the project. Generally, a separate environmental impact study is required.[12]

“The most commonly used terms to describe the phases of feasibility in recent years are those adopted by the Canadian National Instrument (NI) 43-101 regulation, which uses preliminary, prefeasibility and feasibility to define the three phases. These terms are used to indicate to the investor what phase of the feasibility study has been completed, and this typically relates to the amount and level of engineering that has been accomplished (not entirely, but largely). Runge (1998) says, “These stages represent “the accuracy of the forecasted returns and that the accuracy of the study at each phase improves, of course, as more engineering effort goes into the study. It moves from ±33% in the second lowest phase, to ±5% in the final phase. This increase of estimate accuracy is certainly common to all of the systems.”[13] Noted above, the author respectfully disagrees with Runge on this point, since greater precision in engineering studies does not eliminate the greater mining and business case uncertainty, and suggesting that engineering studies can deliver a forecasted return accuracy of ±5%, is simply incorrect.

Peter McCarthy, Chairman Emeritus and principal mining engineer at AMC Consulting, notes that around 25% of projects fail, a further 20% perform better than expected and the remaining 55% perform as expected. From AMC’s experience, there is no apparent difference in performance between junior and major companies, large and small projects, or locations around the world. There remain many risks and uncertainties, even after the publication of a bankable feasibility study that can and does result in project failure. In 2011, RL Bullock noted that there have been many studies over the years that reveal the generally poor performance of feasibility studies, with no evidence that estimation accuracy has improved over that period, despite the use of computers. He suggested that a feasibility study should be considered a failure if:

• The capital cost is higher than expected,

• The operating cost is higher than expected,

• The recovered grade is lower than expected,

• Sales revenue is lower than expected,

• It takes longer to build and ramp up than expected, and

• Initial performance cannot be sustained, though it may take several years for the failure to become evident.

If this is the yardstick, then most projects fail, since the uncertainty around sales is significant, because commodity prices cannot be accurately forecasted; they are uncertain. More fundamentally, McCarthy points out that an often-inadequate understanding of the geology of the deposit being considered is often the root cause of project failure.[14] So while it may be thought that greater engineering rigour in quality and definition of engineering aspects of design, build and operate increase confidence to ±5%, is a rather disingenuous claim. This is perhaps the reason for the dissatisfaction of investors, who believe that feasibility studies are often not fit for intended purposes, and complain that feasibility studies have tended to bias focus on technical issues at the expense of critical business and project delivery issues.[15]

This is not to say that technical issues are unimportant. They are a prerequisite to the demonstration of a project's feasibility,[16] but to narrowly define and bias the feasibility study is to fail to fully understand the driving forces that influence value creation. Chief among these driving forces are the ore deposits themselves. Often miners suggest that orebodies dictate outcomes, but in practice behave quite differently. Ergo, “the feasibility study process must demonstrate, that not only have the technical issues been satisfactorily addressed, but also that the broader commercial, economic and social issues have been considered in the development of a comprehensive business plan, which includes an assessment of the risk-reward profile of the proposed development.”[17] Ultimately, the goal of utilising an exhaustible resource lies in its economic value. Economics, says Runge (1998), is a key skill and essential partner to technical skill at every step of the mining process. Hence understanding the economics of each peculiar ore deposit must be a pre-requisite to any engineering design.

Mackenzie and Cusworth crafted an enlightened feasibility framework that better describes the progression of feasibility studies shown in Figure 20. This framework, while not explicit, follows the basic principles of Design Thinking. The emphasis on understanding multiple alternatives, and the concept of viability is clearly a step change in thinking. The shortcoming, however, is that any reference to the ore deposit and its embedded optimisation is absent.

Feasibility studies are fundamentally a multi-disciplinary endeavour that begins with strategic intention being explicitly provided. Strategic planning and development strategy crafting, is “a key phase when critical decisions are made concerning the development strategy and alternatives, with substantial differences in economics which are eliminated. Following this phase, the economics of the mining operation is largely fixed, since changes in strategic direction have major influences on costs, risks and capacity to accommodate change.”[18] Hence understanding the viability of an ore deposit early on is a critical step, often missed by engineering approaches. Separating the definitions of viability and feasibility, as done in Design Thinking, offers a pathway to better describing an approach that inserts a more robust economic approach to mine design and mine management.

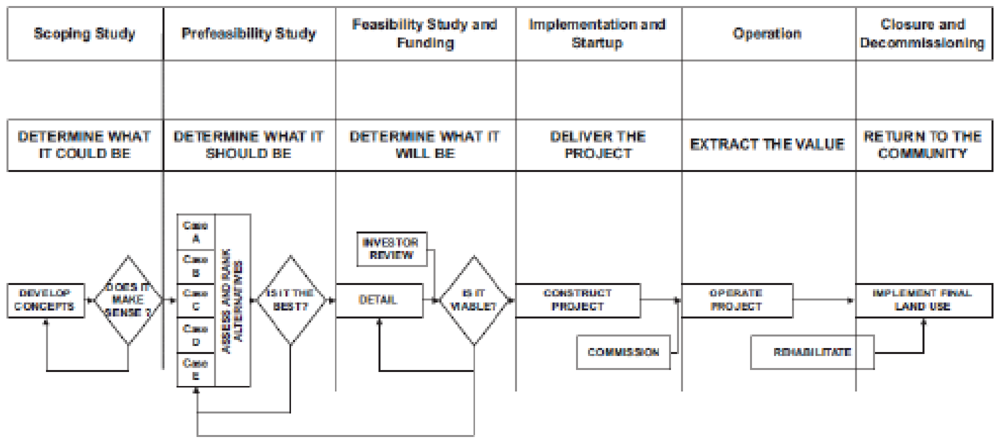

Figure 20: Project Development Framework

Design Thinking provides an augmented approach to feasibility studies, and this new approach can provide space in the study phase to recognise the primacy of the ore deposit more fully, and to allow the economics of the ore deposit to dictate design outcomes. Design Thinking, far from being a radical divergence from the current process of strategic mine planning, is a highly complementary addition that can better harness and coordinate the multi-disciplinary nature of mine design, and focus activities and outcomes on the realisation of the critical criteria for an organisation to fully utilise and optimise mineral resources, with the aim of maximising economic value.

III. Design And Innovation Thinking

The traditional way of assessing a mining project is for geoscientists to define a mineral resource, and then to pass the baton to mine designers who design and develop a mine based on the mineral resource defined. There is no requirement when declaring an ore reserve that the ensuing business plan should or must maximise the economic utility of the ore deposit to be mined. More often than not, the business plan demonstrates that the minimum corporate hurdle rates can be achieved, and even when these minimum hurdle rates are exceeded, the full economic potential may still not have been fully explored. Lane (2015) states, that the only sensible way to fully understand the maximum potential of an ore deposit is to set cut-off grades that maximise the net present value of the mining operation. McCarthy suggests that the Hill of Value, the trade-off between production scale and grade, be created to understand the utilisation of the ore deposit in an economic sense.

There remains, however, a disconnect between those who manage the corporate business and those who design and operate the business. Lane (2015), recounting answers for the determination of a cut-off grade, listed the following:

- We have always worked to 0·3%;

- Head office decided 5% combined metals some years ago;

- That is a technical matter; we leave it to the people on-site;

- I think several cut-offs were examined in the feasibility study and 1%

- seemed best; and

- I guess our costs are running at $10 a tonne and uranium is worth $10 a pound, so 1 lb/tonne must be about right.

The answers clearly reflect the disconnect between those who manage and those who operate. The status quo runs deeper, however. Often at times there is also a disconnect between those who manage and those who plan and design, and those who design and those who manage. While there have been significant strides in strategic mine planning, there still remains a critical disconnect, driven by the siloed approach to mine design. Design Thinking offers a solution.

Design Thinking by definition is a multi-disciplinary approach. It draws on the skill, expertise and experience across the organisation and integrates the strategic desire, the requirements for business success and the possibilities of technology. In so doing the organisation can unlock innovative approaches to problem solving, which often result in disruptive solutions that provide the organisation with a distinct competitive advantage.

Initially Design Thinking considered the trifactor of desirability, viability and feasibility, but more recently, sustainability has been added to the circle matrix shown in Figure 21. This addition is not only complementary, but an important sphere, considering the growing and significant emphasis on sustainability within the global marketplace generally, and more specifically to the mining industry. The topics of environment, social and governance that are considered key elements of sustainability, are however beyond the scope of this book. Sustainability will, for the purposes of the book's subject matter, be considered from a narrow economic perspective. This is not to disregard the wider definition of sustainability, but that deserves better attention, save to say that "if a mine is planned in such a way as to maximise its net present value (excess of present value over capital costs), then in theory there is more wealth to share between all stakeholders. Everyone could be better off. Whether in the event, they are or not, depends upon the nature of the agreements between them, but this is a huge subject in its own right."[19]

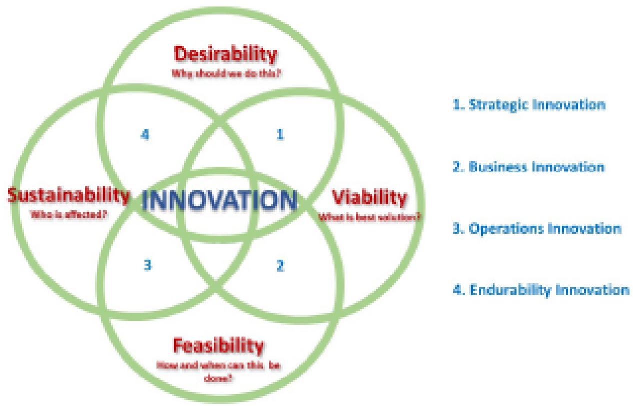

Figure 21: Design Thinking and Innovation

When design principles are applied to strategy, innovation becomes the driving force within the outcomes of strategic planning. Since “major S&P companies, such as Apple, Pepsi, IBM, Nike, Procter & Gamble and SAP, that have outperformed the S&P 500 over a 10-year period by an extraordinary 211%, have adopted Design Thinking,”[20] it may be that the mining industry can greatly benefit from this approach when designing and operating mines. The mining industry is often at the forefront of accelerated change, and as change has accelerated, so has complexity. “Prior to the Internet, business strategy tended to follow a traditional, linear process that included analysing data to identify challenges and solutions from the relative safety of the boardroom. Business managers studied dizzying printouts of P&L’s and market data. They sat around conference room tables talking about all the usual suspects they learned about in business school, or from their years of experience. Maybe they held a focus group or deployed surveys. Then they let all that data point them toward the likeliest culprit and devoted resources to the most effective solution.[21] By contrast, Design Thinking is a non-linear, iterative process that teams use to understand outcomes, challenge assumptions and paradigms, redefine problems and create innovative solutions. The process of Design Thinking fosters innovation because it helps teams structure interactions to cultivate greater inclusiveness, foster creativity and align participants to make sense of complexity, because the framework links the processes and harnesses ideas that were strictly siloed in linear thinking. Design Thinking is versatile and has been applied in organisations to:

• Redefine value;

• Reinvent business models;

• Align shifting markets and behaviours;

• Promote organisational culture change;

• Face complex societal challenges such as health, education, food, water and climate change; and

• Resolve problems affecting diverse stakeholders and multiple systems.

All of these pointers have relevance to the mining industry, as does the application of Design Thinking. The subject matter of this book, however, focuses primarily on redefining value. Since the primary economics of the mine are largely set in place by those factors that impact the revenue, understanding those factors (i.e. orebody characteristics, grades and recoveries and market equilibrium prices), mine design and mining plans must be adaptable enough to accommodate the changes necessary to be viable, despite uncertainty of outcome.[22] It follows that linking the ore deposit to economic factors which influence the whole mining process is fundamental to defining economic value, since mining operations earn revenue and incur costs, and estimated value can be ascribed to it. The application of Design Thinking allows miners to understand how to maximise the economic utility of an ore deposit in a structured non-linear fashion, by linking, harnessing and harmonising ideas across the value chain. The outcome is better alignment of ideas and behaviour, simplified processes, cost reductions, innovation and creation of disruptive technologies, among other benefits.

Desirability

Desirability is essentially understanding: Why are we doing this?

At the time of penning this book, rising commodity prices suggest that the world is on the cusp of a second commodity boom as the world retools for a “green” world. This fundamental social shift is driving demand, and demand is adjusting equilibrium pricing of many commodities considered critical for the carbon-free economy. Miners are tempted to consider focusing on what are now termed battery metals, and switch from commodities that support the carbon-based economy.

A typical strategic analysis followed by many organisations is illustrated in Figure 22.This strategic map implicitly describes Design Thinking. The initiation of the strategic process is an attempt to understand the macro and micro dynamics, and to match them with business capability. By understanding the macro trends and micro (company) competencies, the business is able to understand the opportunities that can be taken advantage of. Opportunities come with risk and/or potential threats, and organisational weaknesses that must be clearly thought through notwithstanding the organisational strengths, to capitalise on the opportunities that present themselves.

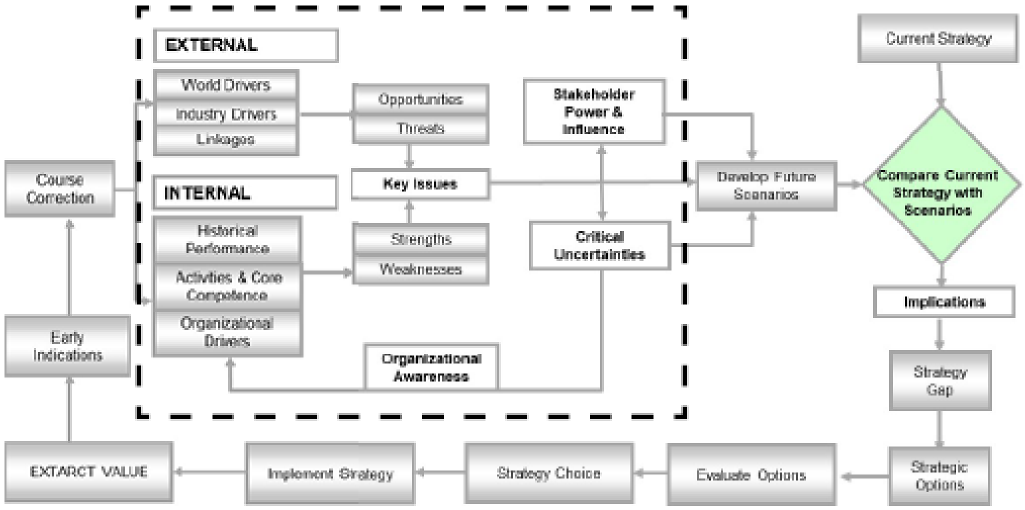

Figure 22: The Strategic Cycle

During the last super-cycle, it is clear that insufficient formal strategic analysis was undertaken. Had a more formalised approach been taken, companies would have identified the looming threat of market oversupply and would have been ready to adjust course in a timely manner. Without reinforcing the poor performance of the mining industry post-2013, had the industry taken more seriously the need for continuing and rigorous strategic analysis, it is most likely that companies would have been more measured and more agile. Take for example, Porter’s Five Forces model, illustrated in Figure 23. Had mining companies thought through this basic model, it would have been apparent that rising prices creates a price incentive for new entrants. Existing competitors believed that existing barriers to entry were too high, namely the high capital costs of entry, but disregarded the capacity of stock exchanges to respond and finance new entrants. Much of the new supply was phantom and existed only because of stock market exuberance. For example, the multiplicity of new entrants into the platinum industry between 2000 and 2010 exploded. Fast forward to 2020 and only the significant pre-commodity boom competitors remain. To counteract the new entrants, existing miners responded by prioritising production in the misguided belief that economies of scale would drive down costs, thereby providing them with a greater competitive advantage. This strategy worked against them, as it fuelled costs and increased supply to the point where supply became inelastic to demand.

Concurrently, as input costs rose, so did the cost of production. The market, realising that higher input costs served as an indicator for the floor price of metals and commodities, began looking at substitution to counter production costs. Thrifting became the main substitution drive, while other auto-catalysts and metal substitutes were vigorously pursued in the platinum industry. As miners lost focus of market dynamics, China's faltering Gross Domestic Product (GDP) was not recognised as an emerging threat. Miners simply continued adding to the supply pipeline. In 2013, prices began falling in response to supply inertia, and the lack of supply response had its inevitable consequences.

While hardened field engineers may consider strategic analysis and an understanding of the desirability of a strategic choice with an academic pursuit, the fallout of the last commodity super-cycle is sufficient cause to demonstrate the necessity of a formal strategic approach in which all mine planning and design is done, notwithstanding operating mines.

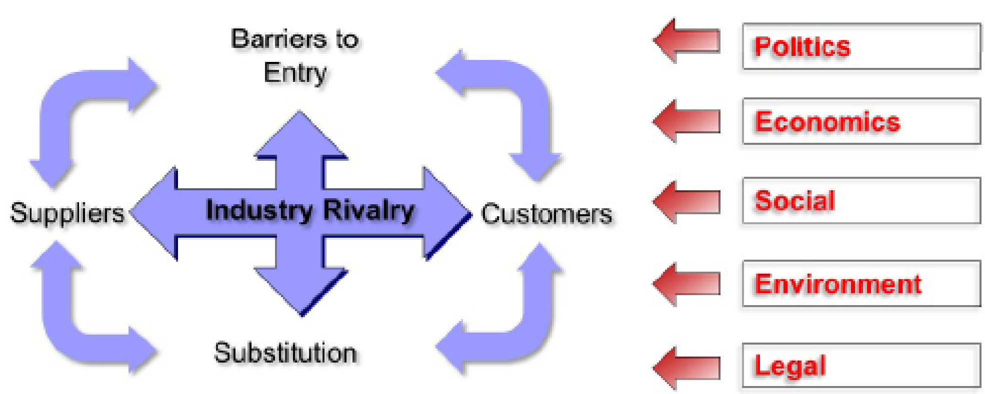

Figure 23: Porter's Five Forces and Pestel Model

Ultimately the pursuit of understanding the desirability of strategic choices and options highlights the key issues at play. In the modern era, the stakeholder power and influence cannot be ignored, and all strategic choice will inevitably face the social licence to operate. Ultimately, desirability concludes with a firm understanding of the critical uncertainties that are required to be modelled in any economic assessment for any project development. It answers the question: Why are we doing this? That answer points the business in the direction of deposit and to target and satisfy the macro-economic needs. In the Design Thinking framework, Desirability talks to Discovery and Definition when considering the mining value chain. Strategically, Discovery and Definition cover exploration activities or mergers and acquisition targets, in order to define a mineral resource to buy or develop, or both.

Viability

Viability is essentially understanding: Should we do this?

Business viability is fundamentally being questioned through the viability lens. In the Design Thinking framework, viability is distinctly different from the concept of technical feasibility. Traditionally in the mining industry, order of magnitude studies (OMS) are initially used to understand a project's viability. By copying plans and factoring known costs from existing projects completed elsewhere, this has been thought to be sufficient to understand an ore deposit's viability.[23]

The intent of OMS is described by Mackenzie and Cusworth as being to:

• Assess the potential of the new or expanded business opportunity;

• Describe the general features of the opportunity, including potential cases to be studied in the next phase;

• Determine key business drivers for the opportunity and any potential fatal flaws;

• Develop order of magnitude costs of the opportunity (both capital and operating);

• Identify technical issues needing further investigation, such as geological drilling or test work required;

• Determine the costs and time to undertake further development work to complete a prefeasibility study;

• Identify the resources, personnel and services required to undertake further work on the opportunity; and

• Provide a comprehensive report with supporting appendices, that includes a recommendation to proceed or otherwise.

Whilst these pointers are all useful and fundamental to considering the viability of an ore deposit, the outline lacks the explicit primacy of the ore deposit. For that reason, many projects have met with failure as the inherent economic characteristics have simply been ignored in pursuit of engineering solutions.

The recognition of the Preliminary Economic Assessment (PEA) by the Canadian Securities Authority (CSA) is evidence of the need to provide more comprehensive and robust economic assessments of the viability of an ore deposit. The CSA describes the PEA as a study for determining the potential viability of a mineral resource, namely:

The "preliminary economic assessment means a study, other than a pre-feasibility study or feasibility study, that includes an economic analysis of the potential viability of the mineral resource."[24]

While the companion policy 43-101CP to the Ni 43-101 states that, “the preliminary economic assessment is based, in part, on inferred resources, which are considered too speculative geologically to have the economic considerations applied to them that would enable them to be categorised as mineral reserves.”

Ergo, the concept that viability is a separate concept from feasibility in the mining industry is well recognised. Dominy (2003) refers to economic viability and technical feasibility when considering the ore reserving process. “Current classifications of mineral resources and ore reserves are based on geological assurance (e.g., characteristics of the ore body, especially geological and grade continuity), data quality (e.g., sampling and assay quality, etc.), and technical feasibility and economic viability under present cost and price structures.”[25] The content of what a viability study and the outcomes require is now the conversation and debate. Introducing Design Thinking is thought to be well timed as it can add significant guidance to the serious quest for maximising utilisation of exhaustible deposits.

Viability from the Design Thinking Framework explores the possibility of the best economic solution to maximise the economic utilisation, and in mining it will focus on the ore deposit economics. Mining companies are simply a portfolio of ore deposits, and understanding each one is fundamental to the company’s business performance and success. Viability therefore gives time to critically analyse an ore deposit’s ekconomic signature and capacity to perform. It is an opportunity to understand the economics and marginal economics of an ore deposit, the scale of operations and an opportunity to consider alternatives to mining and processing. It is about “determining the potential profit that may exist in a new business [project]. The study may come from several different angles, so all aspects of a new idea or business are under review prior to implementation.”[26].

From a strategic perspective, it starts with scenario development and ends with a strategic choice based on strategic criteria. Strategic intent involves following on from desirability that has been considered with regard to commodities, jurisdictions and assets to target. Viability focuses attention on the project or deposit identified. The viability of an ore deposit should be done in an unconstrained manner and is best summarised by Plato's words: "I'm trying to think, don't confuse me with facts." Viability is about challenging the status quo; it's about innovating processes and combining up with disruptive solutions, to drive the economics of the business, generating a multitude of options and outcomes for the business of viability studies. The goal is to maximise the ore deposit's economic utilisation and convince shareholders who will finance the project, that the business viability is robust.

Ergo, viability studies should not be constrained by feasibility constraints or considerations. Elon Musk would never have developed booster rockets that return to earth, had he been constrained by what was considered technically feasible. Musk considered the possibility and the science. Mines of the future will be driven by understanding whether an approach is viable, rather than what is currently feasible. The relentless drive to maximise utilisation challenges the engineers of the day to innovate, and that is how cyanidation, drone surveying, advances in underground mining, etc. began. An environment that was not constrained by what is possible today.

There may not be disruptive breakthroughs at every turn, but there may be incremental advances that, when all told, may be as equally disruptive as a single major innovation. An ore deposit's economic signature must be fully understood and the pursuit of unlocking the value of that deposit must be fully explored. Alternative by-products should be considered (if they are present in the ore deposits), multiple mining methodologies should be tested to compare bulk mining to selective mining, and multiple metallurgical options should be considered, amongst other brainstorming. Since each ore deposit has its own unique economic signature, considering the economics ahead of mine design is essential to maximising its utilisation. Moreover, viability studies set the basis for providing the key economic parameters for the mining design team, when executing the feasibility study. Viability must be the junction where science, engineering and economics collide and combine to create innovative ways to maximise a deposit’s economics.

Modern computing provides a unique opportunity to create the necessary sophistication to consider (as Lane has suggested) all the elements of the value chain. What is being assessed, is the mining operation that exploits an exhausting asset. Nothing of the asset is certain; it relies on statistical probability. For that reason, computing allows for Bayesian and classical statistics to merge, and to hold the understanding of the expected outcomes that will then serve as the foundation for value engineering.

A further goal of the viability study, is to test the optimal scale of future operations that will deliver the maximum economic benefit, by minimising capital, minimising costs and maximising cash flows. To achieve this, a means to test the optimal production rate, alternative microeconomic cost curves, cut-off grades and average grades, must be determined. The viability study should result in defining the mining inventory upon which the ore reserves can be constructed, because the viability of the optimal cut-off grades and rate of production have been determined by the construction of a Hill of Value.

Feasibility

The feasibility study is inherently an engineering study to understand technical design and business resourcing to ensure efficient production. Burdening technical staff, untrained in microeconomics, has led to not only delivery inefficiency with regard to significant projects, but also and in many instances, sub-optimal economic utilisation of an ore deposit. Whilst the unreliability of feasibility studies is well documented, the sub-optimal performance of mines based on feasibility studies has not received sufficient attention. A clear lack of understanding of the economic capability and capacity of an ore deposit is seldom considered by technical people.

Whilst there is no international agreement (at the time of writing this book) on the terminology for each stage of feasibility study, there is also no agreed standard for quality or accuracy. An attempt by the AusIMM's Monograph 27, Cost Estimation Handbook (second edition 2012),[27] attempts a set of standards that may become more widely used. The outline of the standard can be summarised as follows:

A Preliminary Feasibility Study (PFS) is primarily to assess the practicability of the business or project, and to provide an acceptable level of due diligence to support investment. The level of engineering detail and suggested level of accuracy at ± 25 - 30% is sufficient to support the definition of an ore reserve and to approach investors and bankers for funding requirements.

After Mackenzie and Cusworth, the following details should be considered for PFS:

• Assess the technical feasibility of PEA study recommendations;

• Consideration and elimination of different mining options;

• Consideration of the feasibility of alternative processing options and project configurations;

• Examine the potential for fatal flaws of the PEA recommendations;

• Determine the most feasible value maximising option, determined by the PEA;

• Outline the critical features of the recommended project;

• Determine the nature and extent of the further geological, mining, metallurgical, environmental, marketing or other work needed, to be undertaken during the feasibility study;

• Determine the costs and time to undertake this work and prepare a feasibility study, including an estimate of the costs and time to develop the project, following completion of the feasibility study;

• Identify the resources, personnel and services required to undertake further work on the opportunity; and

• Provide a comprehensive report with supporting appendices, that includes a recommendation to proceed or otherwise.

Bankable (Detailed) Feasibility Study (BFS) follows the Pre-feasibility Study and is primarily undertaken to demonstrate, that sufficient engineering design, project scheduling and detailed project budgets have been undertaken and developed to support the investment case. The BFS is the stage gate for debt structures and off-takes to be finalised, and for project initiation.

The engineering accuracy targeted is ±10%, provided that a significant portion of the formal engineering is completed, although this is seldom the case because cost overruns still occur in the order of +25%.

Mackenzie and Cusworth recommend that the following details should be considered for PFS:

• Demonstrate the detailed technical feasibility of a business opportunity, based on the proposed project;

• Define the scope, quality, cost and time of the proposed project;

• Demonstrate the investment case;

• Demonstrate that the project scope has been fully optimised to ensure the most efficient and productive use of the mineral resource, capital and human resources applied to the project;

• Demonstrate construction and operational readiness capacity and capability;

• Establish a detailed risk profile and the uncertainties associated with this risk profile, and develop and provide mitigation strategies to reduce the likelihood of significant changes in the project assessment, as set out in the feasibility study; and

• Plan the implementation phase of the proposed project, to provide a baseline for management, control, monitoring and reporting of the project implementation, and establish a management plan for the operations phase.

Once the feasibility studies have been completed, mining entities are able to demonstrate the robustness of the investment thesis, and are then able to embark on the process of capital formation.

IV. Sustainability

Environment, Social and Governance (ESG), has become an important and burning issue. At the heart of this social initiative, lies the social licence to operate. Society is demanding greater accountability and transparency, and the groundswell has accelerated. Miners will be worse off for ignoring this requirement. In 2020, ESG investment funds captured more than $50 billion, the aim being to promote the environment and promote social good.[28] ESG has moved from pressure groups and shareholder activism, to mainstream.

Various codes have been developed and are intended to give guidance on how institutional investors, such as pension funds and insurance companies, should execute investment analysis and investment activities. It also looks at how institutional investors exercise their right to ensure that they are promoting sound governance.[29]

The advent of the Internet means that information is transmitted at warp speed across the globe, and consequently driving greater transparency. When companies present their values on their websites, these values can no longer be considered as useful window-dressing exercises. Shareholders have started demanding integrity and transparency, and the starting block is to hold companies accountable to their values and to society's demands.

The scope of ESG and its contents is deserving of its own separate discourse, and is beyond the subject matter of this book, save to acknowledge it as an imperative in the strategic framework of a miner. Since the subject matter of this book is about the economics of the utilisation of ore deposits, sustainability is focused on the economic sustainability of a mining business. Since a miner's business' economics cannot be divorced from the broader sustainability issues, it would be remiss not to include this in Design Thinking.

The optimisation of an ore deposit can demonstrate that the interests of shareholders and stakeholders are not necessarily at odds. Shareholders can still achieve alpha returns whilst providing stakeholders, such as employees, extended employment periods, governments with higher taxes, environmentalists with lower carbon emissions and local communities with an economic catalyst. On the governance side, the equitable stewardship of an exhausting resource can be articulated and demonstrated, and this will be unpacked later in the book. While being defined as ESG, Sustainability runs the risk of bias. The concept of sustainability must thus consider all aspects of sustainability, including economic sustainability and shareholder sustainability. Without capital, companies cannot create enterprises that employ people and empower stakeholders, and thus no capital incentives for investors leaves no ESG to speak of. The capitalist system has proven to be a robust system for ensuring efficiency and delivering innovation, and thus ensuring that the mining economics are sustainable in the purest sense will underpin the efforts of the broader ESG intent.

V. The sweet spot

- **Desirability: Why are we doing this?**
  - Macroeconomic trends impacting metal demand
  - Sovereign risks
  - Technology advances
  - Regulatory incentives
  - Social stability
  - Environmental impacts
  - Industry drivers
  - Business competencies and strengths
- **Viability: Should we do this?**
  - What is the minimum investment threshold required?
  - What is the maximum potential return on investment yield?
  - What are the options to maximise returns?
  - What is the optimal design scale?
  - What is the maximum sustainable life cycle?
- **Feasibility: Does the business have the capability?**
  - Does the business have the required resources?
  - Determine skill and systems requirements and availability?
  - What are and how long will alternative economic options take to implement?
  - Is the project aligned to investment criteria?
  - What are the engineering risks and threats?
- **Sustainability**
  - Economic resilience of the asset utilised
  - Skills and people to deliver results
  - Social licence to operate
  - Environmental impact and business choices
  - Strong corporate governance and corporate values

The pursuit of Design Theory is innovation, and the intersection of desirability, viability, feasibility and sustainability is innovation. The Sweet Spot. Innovation challenges thought barriers and forces resolution of contradictions. In 2017 an article was published in The Scribe, on the Pros and Cons of Reusable Rockets, and the article summarised the scepticism. "It is quite possible that SpaceX will be able to make fully reusable rockets in the near future. While this is exciting news, the implications of this new technology should be examined sceptically, and without reckless eagerness."[30] Fast forward and "SpaceX has become adept in the past two years at bringing first-stage boosters home after they have completed their primary task of getting a payload out of the thicker lower reaches of the

atmosphere."[31] In the mining industry and when considering which ore deposits to target, Desirability is about assessing which commodities will render maximum shareholder value, necessary to attract capital, and support long-term corporate growth, based on global economic drivers. Viability is the effort in determining the optimal performance of individual ore deposits, to maximise excess economic value and fulfil strategic expectations of targeted commodity bias, while feasibility contends with realising the economic goals, given operational competencies and capabilities, while pushing the boundaries of these constraints and thinking through the barriers to maximise utilisation of the targeted ore deposit. This book will look at sustainability through the lens of economics; however, the Social Licence to operate is a very pressing factor at the heart of the current ESG wave sweeping the business world. Business economics must consider ESG without losing sight that, without rewarding capital, the very cornerstone of modern society, the cornerstone of ESG will collapse.

While the intersection of all the Design Theory lenses results in aggregate innovation, each intersection of each lens can deliver incremental innovation. The intersection of desirability and viability calls for strategic innovation (strategic positioning), and between viability and feasibility business innovation (strategic assessment), feasibility and sustainability (strategic capability) and finally, sustainability and desirability consider social impacts and economic longevity (strategic competence). Each lens has crossovers that require the cooperation and collaboration of multi-disciplinary teams.

To understand the investment thesis for optimal utilisation of ore deposits, the C-suite needs to understand in rapid fashion the optimality of an ore body, and whether it is worth including into the miner's portfolio. The largest operational scale will not necessarily translate into the lowest cost producer, and neither will the longest-lived mine catapult a mining company into the desired Tier 1 performer. Today investors demand reward for the risk taken to develop mining, with all the concomitant risks, and that reward is now measured by the regular payment of dividends. No longer can miners rely on share price appreciation as the driver to attract substantial investment that is required to be patient and weather multiple price cycles. Miners therefore have to focus attention on delivering cash and delivering optimal levels of cash to satisfy the investment thesis upon which the investment was premised. The time of crafting investment theses and then dispensing with them once the investment is made, has passed. Investors now track management's commitments closely, and demand detailed performance updates to the investment thesis expectations.

The collaboration of business development, corporate finance and mining economists is an essential requirement. Projects making the hurdle of maximum returns and improving the portfolio returns need to test the feasibility of mine design requirements to meet the business goals criteria. Critical information such as operational scale and ore reserve cut-offs, operating costs, free cash flow and mine life to target, are essential to provide mine planners [provide mine planners with what?]. All of this can be assessed at the Viability level, well before technical feasibility is considered, saving companies significant time and money. The role of the pre-feasibility is to test these business criteria, given the technical realities that exist, rather than confusing feasibility studies with viability studies. Mining economists, planning engineers and corporate finance personnel are required to drive this process to ensure that not only technical and economic criteria are achieved, but that the long-term accounting measures are considered, to avoid the devastating accounting impairments meted out at the end of the last commodity cycle and thus destroying shareholder value. Delivering the project requires financing, supported by the production of a bankable feasibility study. Once again, mining economists should be refining the microeconomic inputs, as mining engineers detail the engineering parameters. In raising funds, the mining economist should be supporting the corporate finance teams by demonstrating the robustness of the ore deposit and its continued viability through the feasibility process.

Vi. From a Technical Framework to a Strategic Economic Framework

A conceptual economic framework, Figure 24, for extracting value from an ore deposit must clearly describe the value chain, detail the myriad activities required to advance the ore deposit through the value curve, and be clear on the outcomes of each step in the process. There is no benefit in reinventing a framework when much foundational work has already been laid. However, there is much benefit to be gained by consolidating the knowledge into a single construct that draws on the considerable insights that have gone before. It is also an opportunity to revisit the status quo, and to continue challenging assumptions that must be challenged, in an effort to advance the mining industry's adeptness to a changing environment.

As has been described, Design Thinking takes a different approach and looks at projects through four lenses: Desirability, Viability, Feasibility and Sustainability. Adopting such a perspective, allows for microeconomic thought and practice to benefit and influence project design and outcomes. Microeconomics finds its greatest influence through the Viability lens. It allows for science and economics to blend and not be confused by the constraints of the day. It drives innovation, challenges the possible and unshackles design engineers' thinking, giving them the latitude to engineer solutions.

Desirability drives the exploration and/or the M&A activities of a miner, and should be informed by the scenario planning as alluded to in the preceding chapter. Since ore deposits are exhausting assets, miners have to continually seek replacement ore to remain in business. Ergo, the desirability of the portfolio in a changing and dynamic economic environment requires regular attention, and so scenarios of the future and how they influence strategic direction is a fundamental sphere for boards and C-suite executives.

Viability is the stage at which greater definition of an ore deposit is initiated. It has, at its root, the investigation of what the investment thesis “could be” and also what it “should be”. Traditionally, “order of magnitude” studies (OMS) have been conducted to drive the defining of the deposit’s economic potential and the determination of a mineral resource. Since by definition, a mineral resource simply has to show that there is a case for eventual economic extraction. OMS provides the basis to achieving that status when married to the scientific rigour required to support it. Typically, geoscientists calculate economic cut-offs that have as much rigour as OMS. The author is convinced that the mineral resource’s cut-off should be driven by science rather than economics, as this enables a greater mineral resource definition without violating code practice. Eventual economic extraction means eventual economic extraction. For example, “0.1% copper shell can be closely correlated to the first occurrence of chalcopyrite, which may also correlate with the first appearance of actinolite, which in turn describes the high temperature bounds of a porphyry system, with a strong geological background at the 0.1% copper cut-off and a good numerical boundary to constrain the estimate.”[32]

The Preliminary Economic Assessment has evolved as a study due to the constraints placed by reporting codes on what can be published as “Bankable” or “Definitive”. Whilst nothing is “Bankable” or “Definitive” in mining, given that everything relies on probability and the most unconstrained variable being the commodity price, these terms are misleading.

Nevertheless, Standards of Disclosure for Mineral Projects within Canada plays the role of the Preliminary Economic Assessment (PEA), and recognises the constraints imposed on the Feasibility Studies with respect to the economic assessments. “A significant change included in the June 30, 2011 revisions to NI 43-101 was a new definition for a PEA. This definition removed the restriction that such scoping studies could only be disclosed if they were undertaken at an early stage of project evaluation, prior to the completion of a PFS. It also allowed a mining company to rescope an advanced stage project, based on either a significant change in new information, or on an alternative mining or processing scenario. Importantly, the rescoped project could include inferred mineral resources in both the production schedules and financial analysis, as long as appropriate cautionary language and other conditions, such as the basis for the PEA and the assumptions made by the qualified person, were met within the disclosure.” (CIM Magazine, 2021)

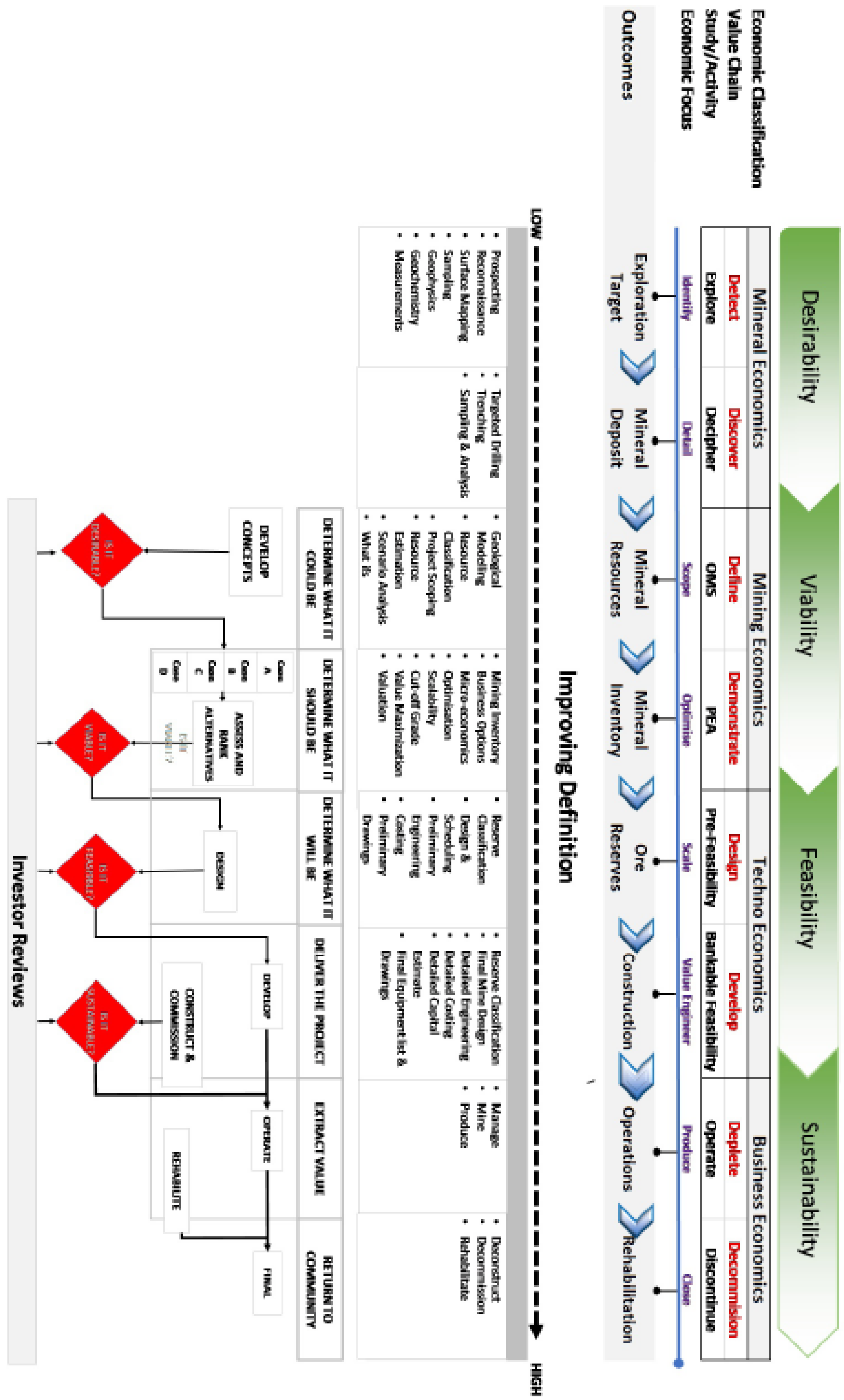

Figure 24: A Strategic Framework for Mine Design

The role of the PEA can be used to define multiple economic pathways that lead to the maximisation of expected value. Options should be considered, and then ranking of the options should be undertaken to provide the economic criteria upon which mine design and planning can continue. The outcome of a PEA should be the generation of a mining inventory, as its intention and emphasis must consider the ore deposit, short, medium and long-term potential and its inherent value proposition. The PEA should be the driver of the feasibility studies, by emphasising the economics of an ore deposit to drive innovation. Divergence from the PEA parameters should only be done on the basis of compelling hurdles in the feasibility study.

Feasibility is the stage when planning engineers take the mining inventory and an option selected by the C-suite, with an understanding of the economic capability and capacity considered at the PEA stage. International reporting codes require that the mining inventory be stripped of the inferred resources, which is a prudent undertaking, considering the inherent risks in mining. The feasibility study must consider the technical feasibility of realising the economic utility of an ore deposit. The feasibility study, however, does not negate the PEA, and both studies must be used for their informational content in any investment thesis.

The scale of operations and optimal mining inventory considered in the viability study should be the foundational parameters for value engineering the deposit through the feasibility hurdles. A natural loop back to the techno-economic parameters may be required, as technical considerations are encountered, such as rock stability, geometallurgy challenges etc., are encountered. The production of an ore reserve is an important outcome of the planning and design phase.

Sustainability is the final stage of mine development and refers to the operating of the mine to yield the expectations of shareholders and stakeholders. Whilst activities of sustainable operations are incorporated in the viability and feasibility activities, they are realised and managed at the operating stage. A vast range of management activities undergird this stage, and microeconomic management techniques can still be engaged, and should be engaged, to ensure that the operations are achieving and maintaining the scale and level of production, notwithstanding the targeted grades that were planned for.

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Chapter 6

Economic Optimisation Modelling

"Recognising the importance of something Is not the same as providing the tools that achieve it."

– Ian Runge 1998

Preview

The objectives of optimisation must be to align the corporate objectives of the owner with the outcome of the feasibility study. "Feasibility studies are commonly constrained by time, budget and data to achieve a minimum economic hurdle without really determining how much better the project could be. The gross variables that require optimisation are the cut-off grade, production rate, mining method and process design. Whilst mining method and process design are key technical feasibility issues, cut-off grade and production rate are fundamental in determining various combinations that will yield maximum economic gain."[1]

Kenneth Lane considers NPV maximisation as the principle metric to optimise the economic value of an ore body, hence his adoption of NPV as the basis for establishing the economic definition of the ore and defining the ore body limits. In his opinion, material from the mineralised body should be scheduled for mining as ore, if, and only if, the decision to treat it adds to the overall economic value of the operation.[2] Optimisation as described in this chapter is therefore finding the economic moments that maximise the value that an ore body can deliver under a set of economic conditions.

This chapter will describe two microeconomic optimisation models that underpin the economic factors which influence the whole mining design and process. These two models, when combined into a single dynamic optimisation construct, are used to test the viability of a peculiar ore deposit. The full modelling technique considers all the factors necessary to understand the ore deposit's economic feasibility, and therefore includes market prices and costs, grades and cut-offs, recovery factors, etc., to construct a Hill of Value. Despite NPV being the principle metric being optimised, the dynamic nature of the modelling allows for any metric defined and described, to be optimised.

KEY CONCEPTS

- Optimal Cut-off Grades
- Optimal Economic Production Rates
- The Mechanics of Optimisation

I. Ore Deposit Optimisation

A number of factors must be considered when optimising an ore deposit. Maximising the NPV is the only objective measure to determine the optimal utilisation of an ore deposit, from an economic perspective. In Figure 25, the key optimisation elements are illustrated. Ultimately, determining the optimal cut-off grade and the optimal production rate is the key to maximising the NPV. The cut-off grade is influenced by the assumed long-term commodity price, and the cost of production which determines the rate of production, and which in turn affects the rate of metal output.

Maximising the NPV has to consider the capital requirement to build an intended mine design. The larger the footprint, the larger the capital investment and the greater the risk. Fundamentally, capital requirement is determined by the scale of operations, and the optimal scale (or rate of production) is determined by the marginal cost of production.

NPV embedded the concept of the time value of money, and therefore the construction period duration and the production life or Life of Mine (LoM) materially influence the NPV. Ergo, the scale of operations affects the construction period required, which in turn affects the quantum capital requirement or capital allocation.

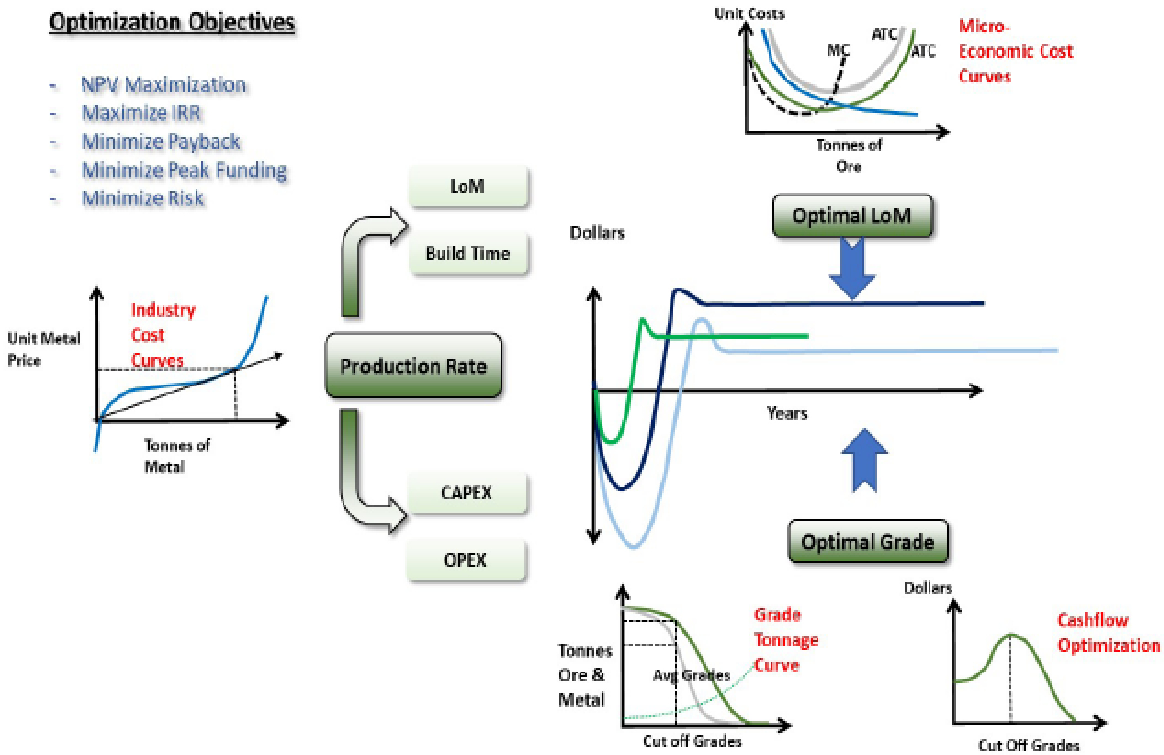

Figure 25: Elements of Optimising Economic Benefits From an Ore Deposit

The rate of production also affects the average grade that will be presented for processing. Typically, as the scale of production is increased, the cut-off grade is decreased to ensure that sufficient ore is available for mining. As the cut-off is decreased, so too is the average grade presented for processing.

The increase in scale on the cost pf production is positive to a point on a unit cost of ore mined and processed, but as the grade reduces, the unit cost of metal rises more quickly, which in turn increases the cost of production of metal produced and ultimately reduces profitability.

The advocates of reducing the cut-off grade to maximise the total metal produced ignore that, while reducing the cut-off grade and extending the LoM, value destruction is encountered as the discounting weighting factors, especially after the 15-year horizon aggressively diminishes the present value of cash flow.

The commodity price assumed in optimisation is a critical variable. The adoption of a long-term commodity price has tortured mining professionals, as it has been shown that time and again, forecasted metal prices, no matter the mathematical sophistication, have consistently been erroneously incorrect. This book will present a technique to guide the adoption of a long-term price based on economic theory, rather than on crystal ball gazing and mad theories.

The interconnectedness of all of these variables makes for a circuitous calculation. Mine planning engineers often contend that the process is iterative. The hurdle overwhelms the planning engineers and as a result, only a limited number of economic options are tested. This torturous process is the root cause for many feasibility studies being unreasonably drawn out, at great cost for miners. Depending on scale, feasibility studies have been known to last more than five years, while some never get off the drawing board, incurring a significant opportunity cost for investors. More often, those that do see the light of day are too often suboptimal economic solutions, both in scale and design.

While many miners stated that the ore deposit dictates their decision-making, many cannot point to a cogent basis to support such a claim. Allowing “the ore body to dictate” is often a confusing conversation at best. Worse, is that too often, miners have very little concept that ore deposit signatures are unique, and fall prey to the idea that a one shoe fits all approach has benign consequences. By integrating the grade tonnage curve and microeconomic cost curves, miners can quickly and robustly determine the unique economic capacity of a particular ore deposit, and better comprehend the required capital allocation to allot to each deposit. This is in contrast to the common black box approach, using sophisticated computer software optimisers, the outputs of which are impossible to validate or challenge. Without fully understanding the peculiar economic signature of an ore deposit, investors cannot have the confidence that their investment is being efficiently maximised.

Ii. The Grade Tonnage Curve

The ore deposit signature is easily illustrated by the grade tonnage curve that lies at the heart of the optimisation technique presented in this book. The grade tonnage curve is simply a cumulative tonnage curve, derived from a histogram of the ore deposit’s distribution. The tonnage histogram classifies the ore deposit’s tonnage volume by grade bins and reveals the statistical distribution of grade and volume shown in Figure 26. The cumulative volumes of the histogram distribution serve as the basis of the grade tonnage curve shown in Figure 27.

The grade tonnage curve is portrayed when the average grade of the ore deposit is overlaid on the cumulative tonnage curve. Figure 28, is an illustration of the grade tonnage curve. The cumulative tonnes are shown on the left-hand vertical axis, the horizontal axis retains the grade class bins and the average grade at each grade bin is illustrated on the right-hand vertical axis. The usefulness of the grade tonnage curve is that it illustrates the expected average grade of the ore deposit at a given grade bin. The grade bins along the horizontal axis, are referred to as the cut-off grades, and these grades represent the minimum grade at which an average grade is achieved, with a corresponding proportion of the ore deposit’s tonnage. As an example, at a cut-off grade of 0.6%, the average grade achieved is 1.435 for a tonnage of 10.4 million tonnes.

It follows, therefore, that as the cut-off grade is varied along the horizontal axis, the amount of total ore varies, as does the average grade. As the cut-off increases, so does the average grade increase, while the tonnes decrease, and vice versa.

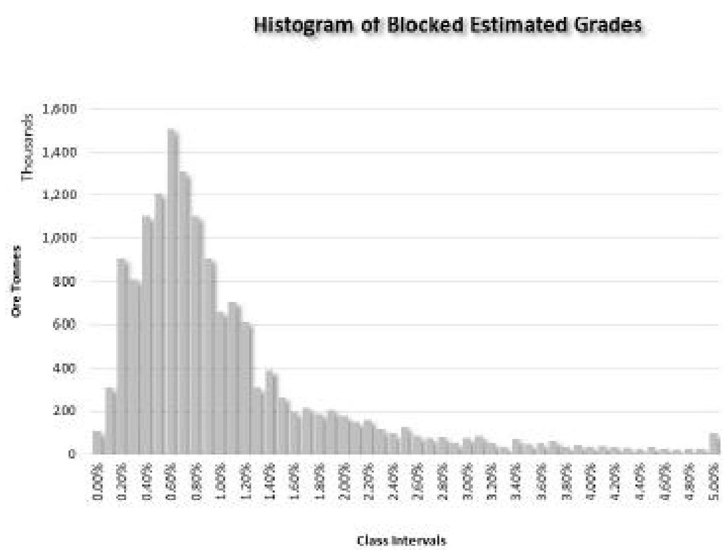

Figure 26: Tonnage Histogram

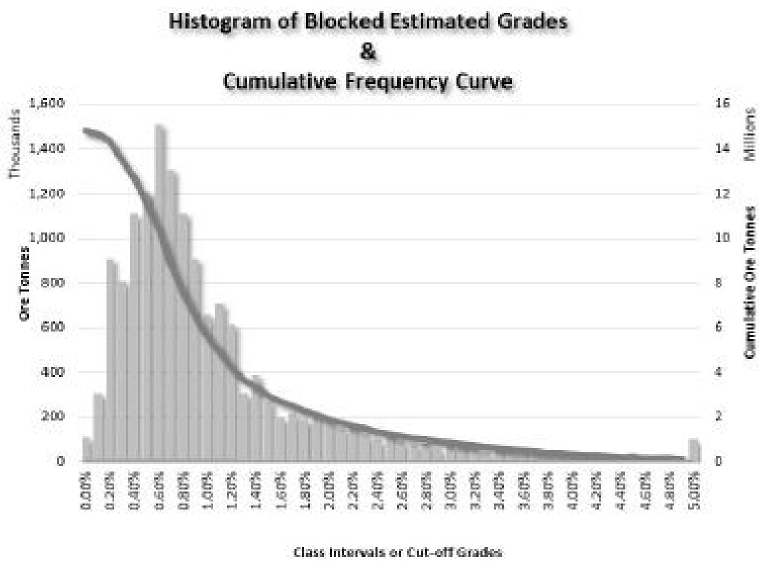

Figure 27: Tonnage Histogram and a Cumulative Tonnage Curve

Herein lies the miner's dilemma. How much of the ore deposit to mine and at what grade?

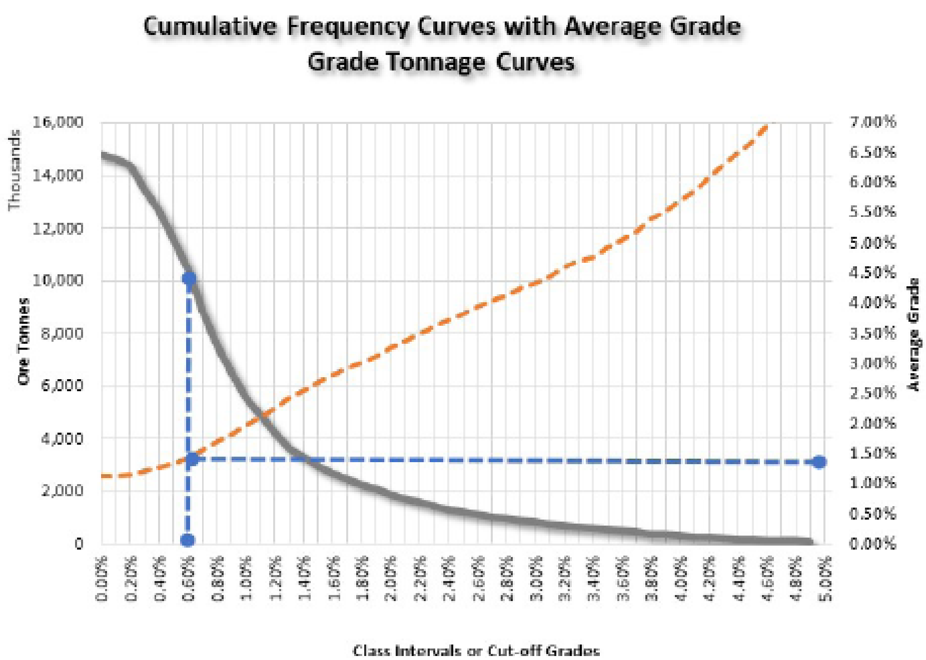

Figure 28: Grade Tonnage Curve

Miners have tended to look at these graphs and concern themselves that by increasing the cut-off, they lose too much potential ore to mine. This anxiety is often misplaced, as the emphasis is not how many tonnes to stuff through the plant; rather it is the amount of metal that can be produced, that is important. Miners default to maximising the LoM, often justified by a notion that large scale makes for a Tier 1 asset, but too often at the expense of optimal economic utilisation of the ore deposit. Consider for a moment, that the more ore mined, implies more absolute cost, as more ore has to be blasted and trucked to the plant to process. This cascades through the design, requiring more tailings storage facilities, more water usage, more power consumption, etc. and the larger the footprint, the greater the environmental impact.

The more ore mined and processed, the larger the scale of operation, and the requirement for greater investment of risk capital. The larger the scale of operation intended, the longer the time taken to build and construct and the longer the payback period. Unfortunately, the consequence of larger scale and lower cut-offs, is that lower grades report to the process plant. Lower cut-off grades means lower average grades, and lower average grades means relative to higher grades, resulting in lower metal recoveries in the plant as a rule. Hence the argument for lower cut-off grades is misplaced, and the incendiary accusation that higher cut-off grades is simply high grading, ignoring the economic implications at the expense of the deployment of capital.

To demonstrate how misconceived the argument about high grading is, a new representation of the Grade Tonnage Curve effectively illustrates these points, and a more objective and unbiased analysis results. Converting the cumulative tonnage curve to a relative cumulative tonnage curve allows for the layering of the metals cumulative tonnage curve, to be superimposed on the traditional grade tonnage curve. The result is that the impact of higher cut-off grades can now be shown in context to the lower potential ore volumes to be targeted.

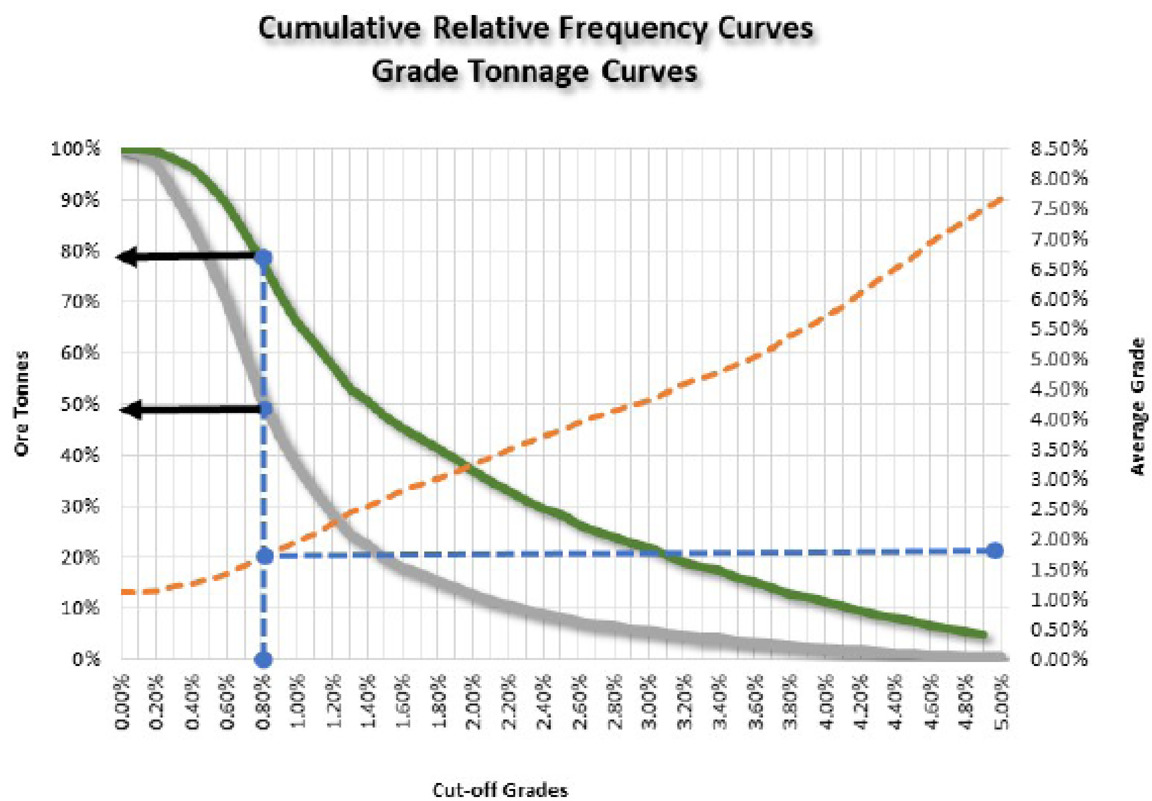

Figure 29: The New Grade Tonnage Curve

In Figure 29, the left-hand vertical scale has been converted to a relative scale, while all other axes remain the same. By increasing the cut-off grade from 0.6% to 0.8%, the available ore is set at 50% of total available ore tonnes. Significantly, this fall in ore tonnes is not reflected in the metal content to be processed, and the grade tonnage curve indicates that at 0.8% cut-off, 80% of the contained metal will reach the plant, while 50% of the ore is processed.

At a cut-off of 0.6%, the potential for 70% of the ore deposit's tonnage exists, but this will only yield an additional ten percent more metal at a lower grade. At a 0.8% cut-off, the average grade is 1.71%, while at a 0.6%, cut-off is 1.43%.

Since every ore deposit is unique, different ore deposits exhibit different grade tonnage profiles, and as a result, inherently different economic signatures exist. Figure 30, illustrates the Grade Tonnage curves for five projects. The slope of each deposit is distinctly different. The movement of the cut-off will have different implications for each deposit. For example, increasing the cut-off grades will have a greater impact on available ore for Project 2, than for the other ore deposits, and the least impact on Project 5. This important observation has a profound bearing on the selection of the mining method and the process design, or should, if economics is centre stage.

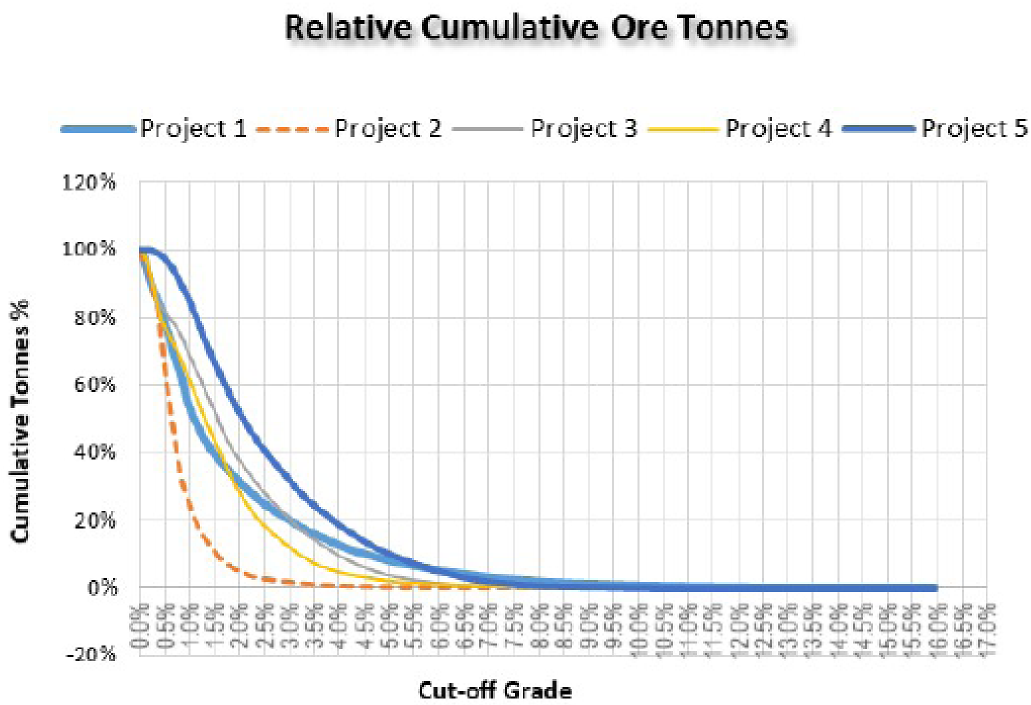

Figure 30: Comparison of Five Orebodies by Ore Tonnes

Figure 31 is equally informative and is the comparative Grade Tonnage Curve when comparing the metal content of each of five projects. The slope of the metal curves generally tend to be less steep than the ore curves. Project 1 still indicates a steep slope, while Project 5 has a pronounced shallow slope. Project 1 will require a high-volume approach to mining, while Project 5 lends itself to a more selective mining approach, to ensure that higher grade and lower cost can be achieved

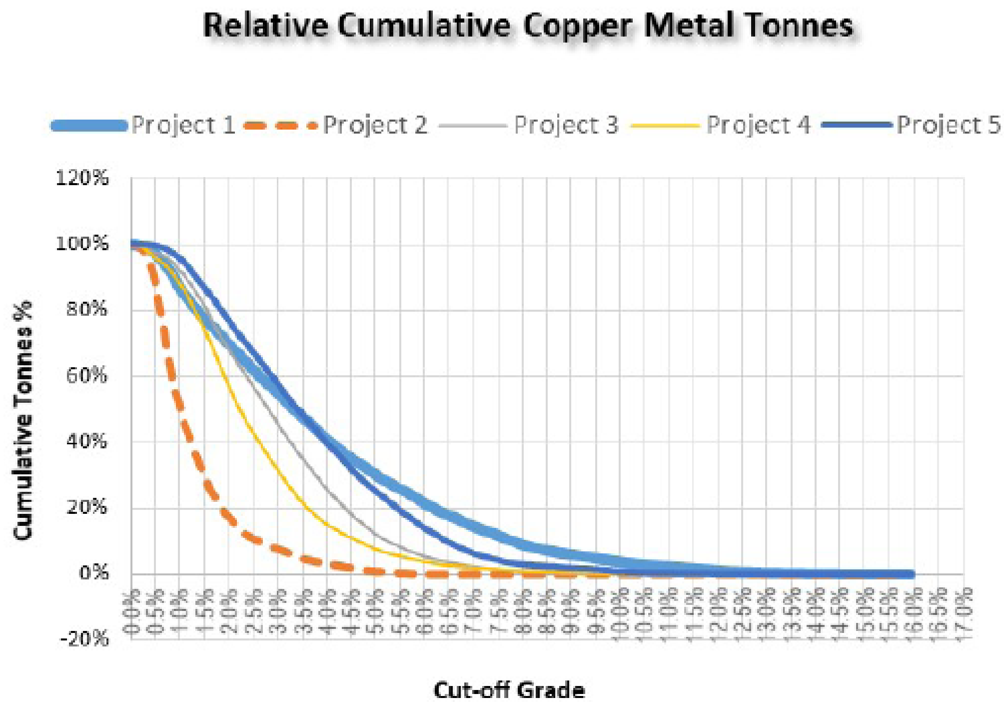

Figure 31: Comparison of Five Orebodies by Copper Tonnes

The miner's dilemma is to determine how to mine the various deposits, to minimise capital investment and maximise investor returns.

Iii. Optimizing The Cut-Off Grade

The implications of a peculiar grade tonnage curve means that each ore deposit has its own unique optimisation moments, as described above. The optimal economic moments need to be determined, given alternative economic and technical assumptions and parameters. The quest is to determine the cut-off grade that will maximise operating income and the NPV for the cost and rate of mining and processing. The simplified model construct to define these optimal moments is illustrated in Appendix 3. This simplified version serves to describe the basic principles of the optimisation model logic used to define the Hill of Value, described in this book.

The objective of cut-off optimisation is to determine the optimal cut-off for the LoM that will yield maximum economic returns. To determine this, the model construct considers the rate of production and its associated cost, straight-lined along the grade tonnage curve, allowing for only the average grades to inform the expected operating profits at each cut-off moment along the grade tonnage curve. In determining the operating profit, the grades are fully diluted, and the assumed recovery discounts are applied to determine the metal yield from the processing plant. Additional variables required to calculate Net Smelter Revenue are also considered to compute the expected Net Smelter Revenue (NSR). Operating profit is defined in the model as NSR, less operating costs.

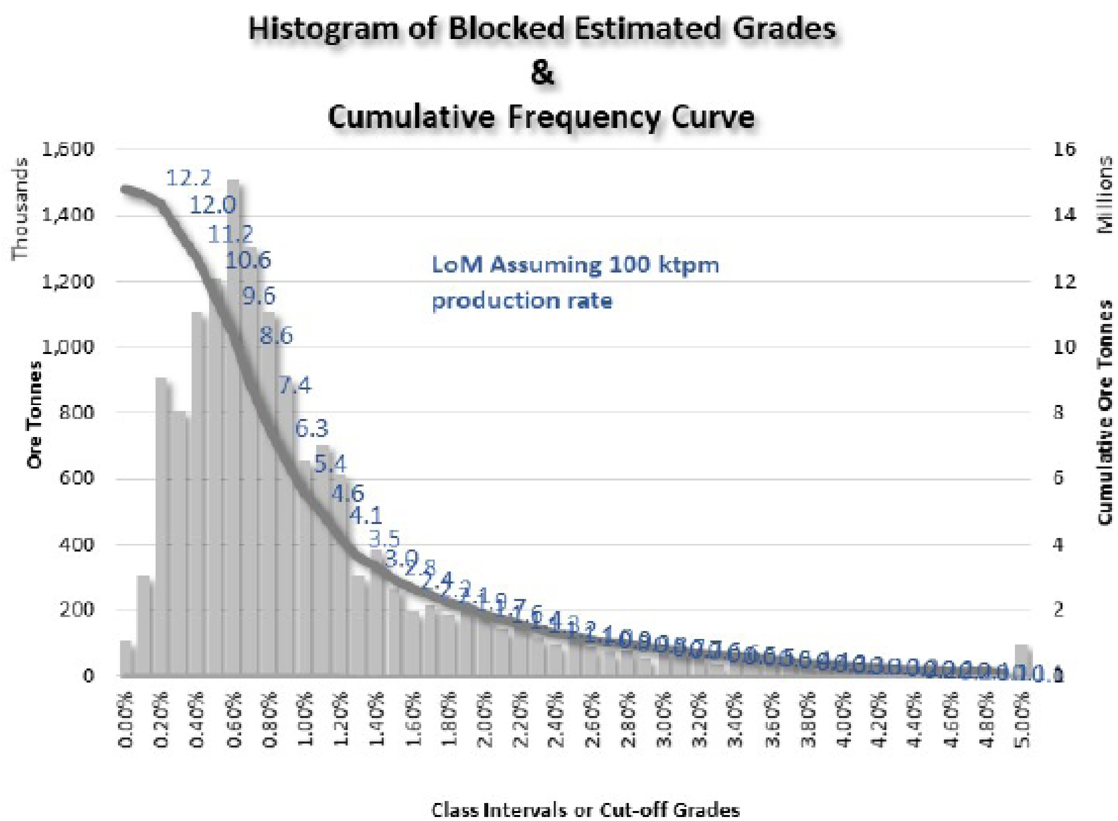

Figure 32: Grade Tonnage Curve and the Life of Mine

As the cut-off is increased, the LoM, determined by dividing the production rate by the total available ore at a cut-off moment along the horizontal axis, decreases as is shown in Figure 32. To determine the optimal economic cut-off over the LoM, the operating profit is multiplied by the LoM and this yields the LoM profits. The result of this is an optimisation curve shown in Figure 33. In this illustration, the optimal cut-off grade is defined at the apex of the curve corresponding to an operating profit of $300 million, with a cut-off moment of 1.15% and an average metal grade of 2.10%. The simplified calculation is shown in Appendix 3. The cut-off grade can therefore be optimised, but it relies on the rate of production and the cost of production. The rate of production can also be optimised using classical macroeconomic concepts.

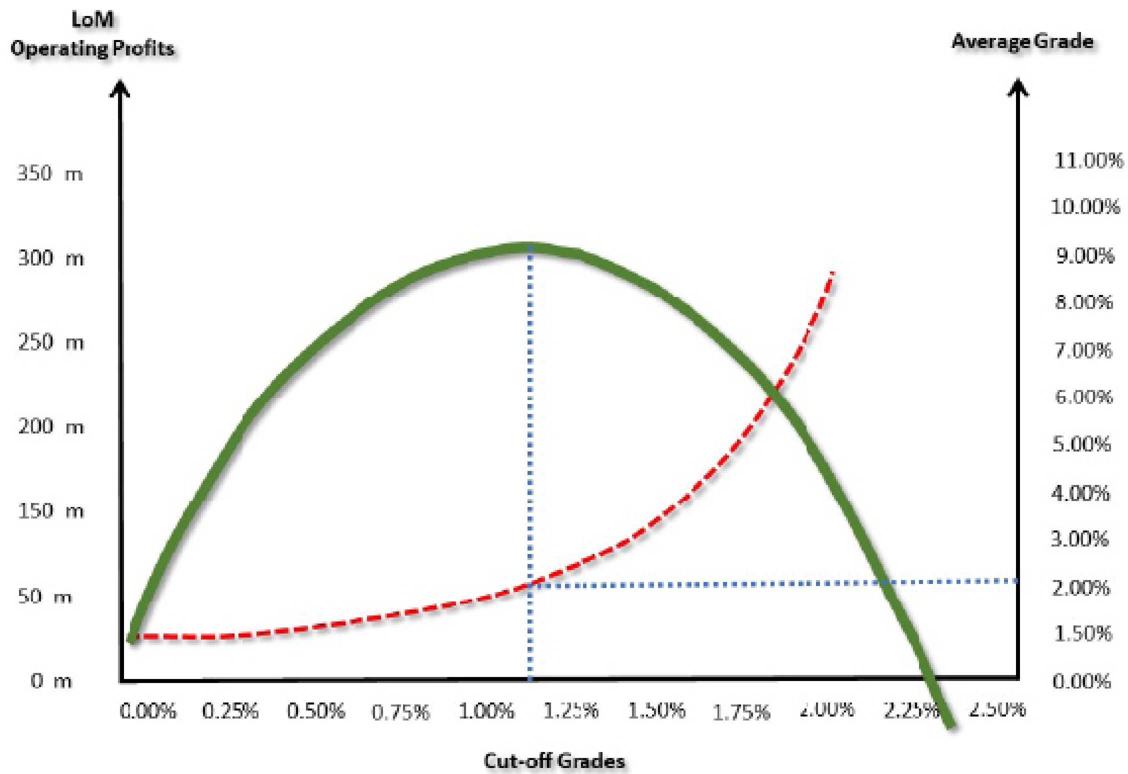

Figure 33: Cut-Off Optimisation Curve

IV. Optimal Economic Mining Rates

"A design rate of mining and processing is selected in every mine feasibility study, although any attempt to optimise that rate is rarely documented. To maximise return on investment, it has long been recognised that both the capital investment per unit of output and the operating cost per unit of output should be minimised. In general, both of these cost measures decrease as the scale of the project increases, so the initial temptation is to 'push the ore body to the limit'. As the operational design scale is increased, so too the technical and commercial risks increase. Factors so often disregarded. Hoover (1909) said, 'The lower the production rate, the lower the required investment, the longer the income stream and the lower the risk to the investor.' While this was well before the advent of Discounted Cash Flow (DCF) analysis, the point made by Hoover remains a good one. Until now, the optimum plant capacity for a new mine has been based on empirical studies or ‘rules of thumb’, subject to confirmation by detailed scheduling of the proposed mining operation.”[3]

The efficacy of these “rules of thumb” has a less than enviable track record, with project failures littering the industry. The most significant causation for underperformance has often times been the underperformance in grade. Too often, miners drive volumes at the expense of grades, when trouble arises. The assumption that “economies of scale” is a panacea for all ills has been well entrenched in the mining industry. This has begun to change, given the realisation from the last super-cycle that the prioritisation of volumes did not yield the expected outcomes, and turned into a race to the bottom. What miners had failed to recognise, was that at some point along the production curve, diseconomies of scale would be and are realised. The double whammy was that as production rates increased, mined grades fell, as lower ore was mined to make up for higher production targets. This effect is known to people at operations but is not recognised in current ore reserve estimation methodology.”[4]

Professor Richard “Dick” Minnitt provides a foundational reference work titled: Frontiers of usefulness: The economics of exhaustible resources, for applying microeconomic concepts to mining operations.[5] This book references his work and reproduces his graphs and explanations. What follows is the determination of the optimal economic mining rate, based on classical economic concepts.

Consistent with the views of Lane, Runge and others, Minnitt also considers NPV as the objective measure to maximise. “The industry objective to maximise the present value of rents (NPV) from the depletion of a mineral resource, depends on the choice of a mining rate over the life of the mine, subject to the constraint that the sum of extraction in all periods, equals the stock of ore in the ground. There is a so-called opportunity cost - rents (plus their interest) that could have been earned if extraction had occurred in the first period, is associated with extraction in each subsequent period. So, rents must be discounted at the rate of interest. Life of Mine is ultimately limited, but is also variable, depending on the rate of production.” [6] The miner’s dilemma, therefore, is to determine the optimal economic rate of production that maximises the LoM and simultaneously maximises profitability as expressed by NPV.

Minnitt generated a hypothetical case to illustrate the determination of the optimal mining rates shown in Table 2. This model relies on classical microeconomic concepts and the nature of costs, more fully detailed in the next chapter. The Total Cost function, is the basis for deriving the marginal costs of production and the basis for optimising the economic production rate for a mine. Belying the marginal cost of production is the concept of Economies of Scale, being the cost advantage of a mine, due to the scale of operation measured by the unit cost of production decreasing as the rate of production increases. At some point, however, the total average unit cost of production begins to rise, and diseconomies of scale are realised. Determining this moment of production is the quintessential quest of optimisation. The point at which the Marginal Cost curve (MC) and the Total Average Cost curve (TAC) intersect is the moment diseconomies of scale exist and the point at which economies of scale terminate. This is illustrated in Figure 34, Point 1.

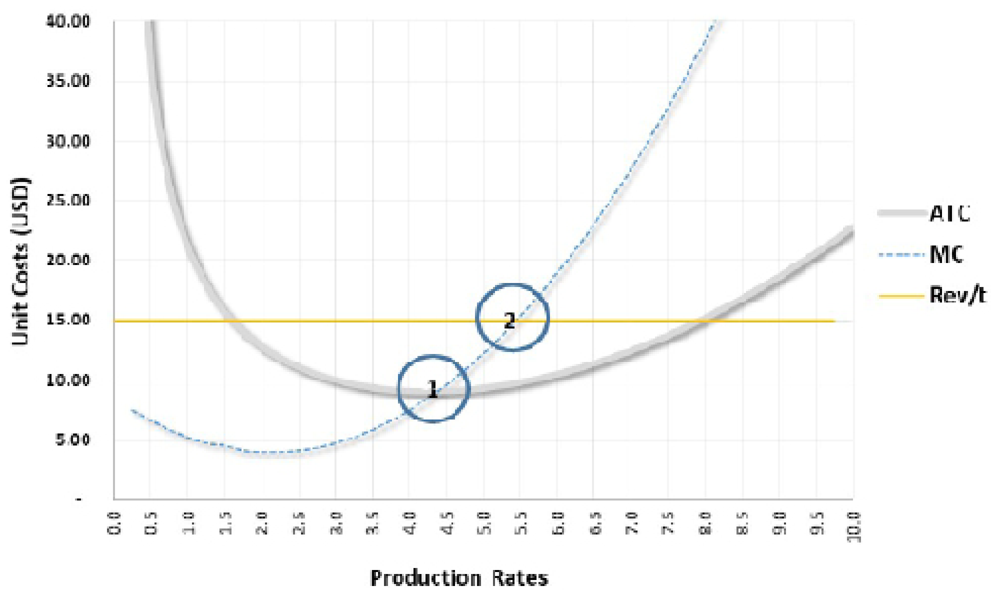

Figure 34: Microeconomic Unit Cost Curves

Two Optimal Moments

Classical microeconomics suggests that the optimal rate of production is where the Marginal Cost of production intersects the Marginal Revenue (MR). The reader is referred to introductory literature on classical microeconomic theory, for proof of this concept. This proof holds that the MR is equal to the Average Revenue (AR) in a perfectly competitive market and represented by the horizontal line at $/tonne 15 in Figure 34. Point 2 represents the moment when the MR = MC, being the optimal rate of production. At this rate of production (5.25 unit of production) profit is maximised at $28.64 and described in Table 2.

"Mine life is ultimately limited, but is also variable, depending on the rate of production. In the hypothetical case presented here, in which the total tonnage to be extracted is 50 tonnes, the rate of production, which maximises net value per year, will not maximise the net value over the life of the mine of its present value equivalent. The optimum rate will be less than this point, because there is benefit in mining fewer units of reserve per year at a lower average cost, thereby lengthening the life of the mine. To reiterate:

At Point 1 Marginal Revenue = Marginal Cost at the mining rate of 5.25 tons per annum and the life of the mine is 9.52 years. At point 1, the minimum Average Total Cost (ATC) is intersected by the MC at the mining rate of 4.25 tons and the corresponding life of the mine is 11.76 years.

The net benefit per year for each of these production rates is:

- At Point 1, $28.64 ($78.75 - $50.11)

- At Point 2, $25.29 ($63.75 - $38.46)

This confirms what we already know: mining at the rate which marginal cost equals marginal revenue maximises net benefits per year. However, if we consider the total net benefits over the life of the mine, we have:

- *At Point 1 Life of Mine profit of $270. $28.64 for 9.52 years; and*

- *At Point 2 Life of Mine profit of $290. $25.29 for 11.60 years*

Revenue	15 USD/t	Discount Rate	10%
Reserve	50		

Production Rate	Rev	FC	VC	TC	Profit	AFC	AVC	ATC	MC	LoM	LoM Profit/10	Profit/t
0.00	-	15	-	15.00	(15.00)							
0.25	3.75	15	1.88	16.88	(13.13)	60.00	7.52	67.52	7.52	200.00	(262.604)	(52.521)
0.50	7.50	15	3.54	18.54	(11.04)	30.00	7.08	37.08	6.65	100.00	(110.417)	(22.083)
0.75	11.25	15	5.02	20.02	(8.77)	20.00	6.69	26.69	5.90	66.67	(58.438)	(11.688)
1.00	15.00	15	6.33	21.33	(6.33)	15.00	6.33	21.33	5.27	50.00	(31.667)	(6.333)
1.25	18.75	15	7.53	22.53	(3.78)	12.00	6.02	18.02	4.77	40.00	(15.104)	(3.021)
1.50	22.50	15	8.63	23.63	(1.13)	10.00	5.75	15.75	4.58	33.33	(3.750)	(0.750)
1.75	26.25	15	9.66	24.66	1.59	8.57	5.52	14.09	4.15	28.57	4.539	0.908
2.00	30.00	15	10.67	25.67	4.33	7.50	5.33	12.83	4.02	25.00	10.833	2.167
2.25	33.75	15	11.67	26.67	7.08	6.67	5.19	11.85	4.02	22.22	15.729	3.146
2.50	37.50	15	12.71	27.71	9.79	6.00	5.08	11.08	4.15	20.00	19.583	3.917
2.75	41.25	15	13.81	28.81	12.44	5.45	5.02	10.48	4.40	18.18	22.623	4.525
3.00	45.00	15	15.00	30.00	15.00	5.00	5.00	10.00	4.77	16.67	25.000	5.000
3.25	48.75	15	16.32	31.32	17.43	4.62	5.02	9.64	5.27	15.38	26.819	5.364
3.50	52.50	15	17.79	32.79	19.71	4.29	5.08	9.37	5.90	14.29	28.155	5.631
3.75	56.25	15	19.45	34.45	21.80	4.00	5.19	9.19	6.65	13.33	29.063	5.813
4.00	60.00	15	21.33	36.33	23.67	3.75	5.33	9.08	7.52	12.50	29.583	5.917
4.25	63.75	15	23.46	38.46	25.29	3.53	5.52	9.05	8.52	11.76	29.749	5.950
4.50	67.50	15	25.88	40.88	26.63	3.33	5.75	9.08	9.65	11.11	29.583	5.917
4.75	71.25	15	28.60	43.60	27.65	3.16	6.02	9.18	10.90	10.53	29.106	5.821
5.00	75.00	15	31.67	46.67	28.33	3.00	6.33	9.33	12.27	10.00	28.333	5.667
5.25	78.75	15	35.11	50.11	28.64	2.86	6.69	9.54	13.77	9.52	27.277	5.455
5.50	82.50	15	38.96	53.96	28.54	2.73	7.08	9.81	15.40	9.09	25.947	5.189
5.75	86.25	15	43.24	58.24	28.01	2.61	7.52	10.13	17.15	8.70	24.352	4.870
6.00	90.00	15	48.00	63.00	27.00	2.50	8.00	10.50	19.02	8.33	22.500	4.500
6.25	93.75	15	53.26	68.26	25.49	2.40	8.52	10.92	21.02	8.00	20.396	4.079
6.50	97.50	15	59.04	74.04	23.46	2.31	9.08	11.39	23.15	7.69	18.045	3.609
6.75	101.25	15	65.39	80.39	20.86	2.22	9.69	11.91	25.40	7.41	15.451	3.090
7.00	105.00	15	72.33	87.33	17.67	2.14	10.33	12.48	27.77	7.14	12.619	2.524
7.25	108.75	15	79.90	94.90	13.85	2.07	11.02	13.09	30.27	6.90	9.551	1.910
7.50	112.50	15	88.13	103.13	9.38	2.00	11.75	13.75	32.90	6.67	6.250	1.250
7.75	116.25	15	97.04	112.04	4.21	1.94	12.52	14.46	35.65	6.45	2.718	0.544
8.00	120.00	15	106.67	121.67	(1.67)	1.88	13.33	15.21	38.52	6.25	(1.042)	(0.208)
8.25	123.75	15	117.05	132.05	(8.30)	1.82	14.19	16.01	41.52	6.06	(5.028)	(1.006)
8.50	127.50	15	128.21	143.21	(15.71)	1.76	15.08	16.85	44.65	5.88	(9.240)	(1.848)
8.75	131.25	15	140.18	155.18	(23.93)	1.71	16.02	17.74	47.90	5.71	(13.676)	(2.735)
9.00	135.00	15	153.00	168.00	(33.00)	1.67	17.00	18.67	51.27	5.56	(18.333)	(3.667)
9.25	138.75	15	166.69	181.69	(42.94)	1.62	18.02	19.64	54.77	5.41	(23.212)	(4.642)
9.50	142.50	15	181.29	196.29	(53.79)	1.58	19.08	20.66	58.40	5.26	(28.311)	(5.662)
9.75	146.25	15	196.83	211.83	(65.58)	1.54	20.19	21.73	62.15	5.13	(33.630)	(6.726)
10.00	150.00	15	213.33	228.33	(78.33)	1.50	21.33	22.83	66.02	5.00	(39.167)	(7.833)

Table 2: Microeconomic Cost Analysis Using Minnitt's Hypothetical Case

Thus, mining at the rate where average total costs are at a minimum, total net economic benefit is maximised over the life of the mine. These optimal moments can be graphically illustrated and shown in Figure 35.

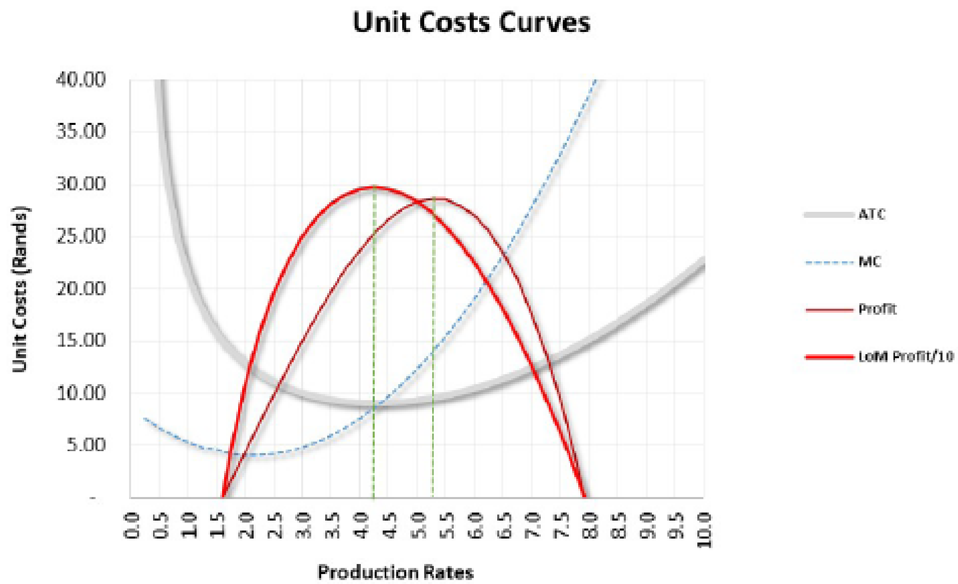

Figure 35: Mine Rate Battery Limits

These two moments are most useful, in that they represent battery limits of operation. The classical optimal point, Point 2, represents annual profitability, while Point 1, represents LoM profitability. This range allows for the operations to extend between the two optimal points for tactical reasons. The mining rate can be increased or decreased in response to temporary falls in metals prices, and a fall drop in metals recoveries, etc., as a short-term measure. In the long term, the owners of the mine would wish to maximise the value of the ore deposit for the LoM, and therefore would want to optimise the rate of production at Point 1.

Effect of Discounting the Ore Deposit

If discounting is considered, the maximum Net Present Value (NPV) occurs somewhere between these two points (Points 1 and 2), and it depends critically on the choice of the discount rate. As the discount rate increases to infinity, the optimum rate approaches the production rate, where MC = MR. As the discount rate falls to zero, the optimum rate of production approaches the minimum AC point.

- As $r \to 0$, optimum production rate → MC = MR rate
- As $r \to 0$, optimum production rate → minimum AC rate

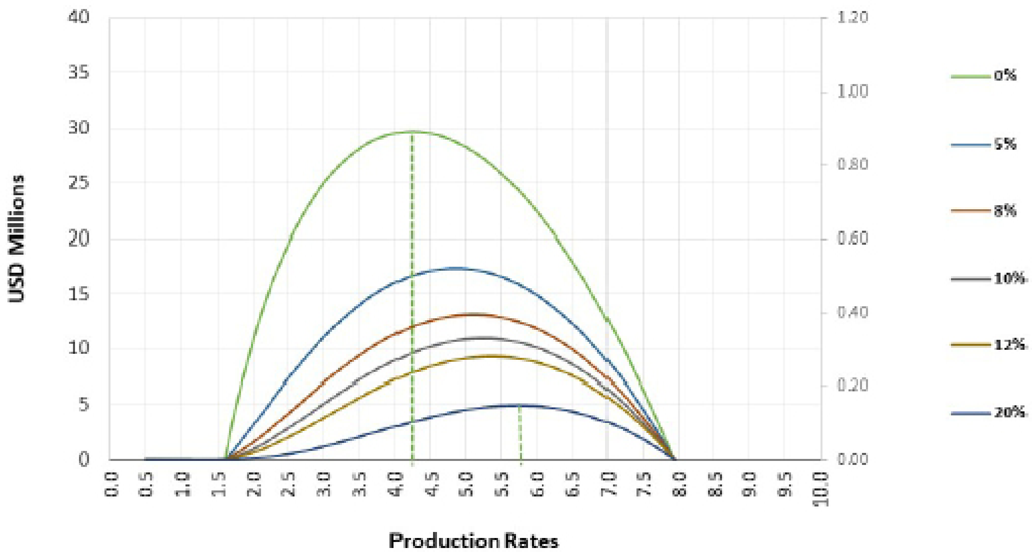

Figure 36: Impact of Discounting on Life of Mine

An analysis of the effects of imposing different discount rates of the production rates is shown graphically in Figure 36. Two clear trends emerge as higher discount rates are applied. The first and obvious trend is that expected NPV is lower, and as this occurs the optimal rate of production increases.

V. The Mechanics of Modelling Economic Optimisation

The optimisation of an ore deposit hinges on the optimal economic cut-off grade and the optimal rate of processing ore, dictated by the marginal cost of production. All other design parameters are yoked to these variables, illustrated previously in Figure 25. The processing rate in the pivotal factor for determining operational scale, which in turn drives the quantum investment requirement and the cut-off grade, is a pivotal factor determining the maximum grade and LoM that the ore deposit can sustain. Ergo, these two factors drive all other design decisions in pursuing the optimal economic utilisation. Integrating these two parameters into a Free Cashflow model, and dynamically simulating the NPV at each interval, underlies the modelling technique used and presented in this book. Simulating multiple NPV outcomes as scale of production increases with alternative cost structures and altering cut-off grades, yields a database of multiple NPV metrics. Mapping these data points results in a Hill of Value, Figure 37 and the determination of the optimal economic scale of operation and cut-off grade, which maximises the NPV for an ore deposit’s peculiar economic signature.

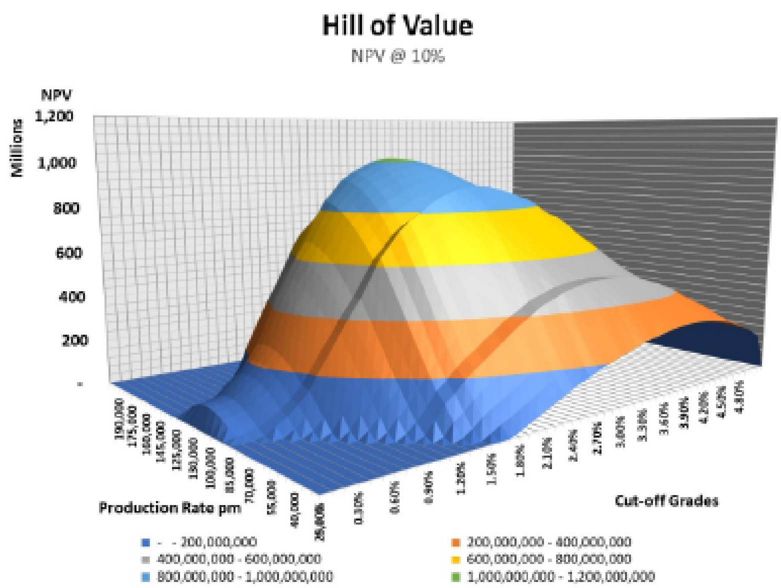

Figure 37: Simulated Hill of Value

Despite the concepts of fixed and variable costs widely accepted and understood, the determination of the appropriate and optimal cost structure is a less well-defined path. Often the cost structures are assigned based on accounting concepts and definition of costs, and once assigned, are assumed to be enduring. The application of Activity Based Costing often yields a different perspective on the fixed/variable costs structure. The approach used in the modelling technique presented in this book is to match multiple cost structures within sensible cost bands, across a range of varying production rates. To accomplish this, the modelling technique runs multiple simulations of the cost structure to determine the maximising moment for the NPV against alternative design choices. The outcomes are directly linked to the ore deposit’s economic signature, via the grade tonnage curve providing the critical test to what the peculiar ore deposit can sustain, by defining the optimal cut-off grade to maximise NPV. This is illustrated in Figure 38, showing how optimal short-run cost curves are sought to optimise the ore deposit cut-off grade.

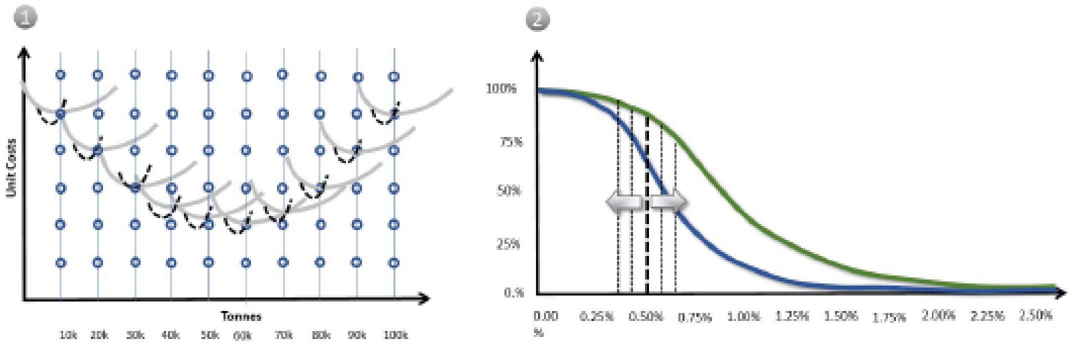

Figure 38: Short-Run Cost Curve Simulation Linked to Grade Tonnage Curves

The feasibility process is now directed by the value maximising requirements, rather than the feasibility constraints being unchallenged and simply accepted. The final feasible option determined at the feasibility stage can be compared to the maximising viable option and the level of innovation applied by engineers considered.

The key stages of the simulation design are illustrated in Figure 39: Key Simulation Steps. Starting from left to right, the simulation initiates by considering the grade tonnage curve, or the ore deposit's intrinsic economic signature. The total cost function is applied to incremental levels of production against alternative cost structures within cap and collar range. The cost structure options consider alternative fixed and variable cost combinations, starting from a 0% fixed cost to a 100% fixed cost base. At each node, an optimal production rate is discovered for each alternative cost structure, and the optimal cut-off grades and average grades moments are established and recorded. The stored data then enables the modelling of Hills of Value. Hills of Value for both operating profits (contribution analysis) and NPV can be constructed, indicating the rates of production and cut-off grades that will maximise cash flow from the ore deposit being mined.

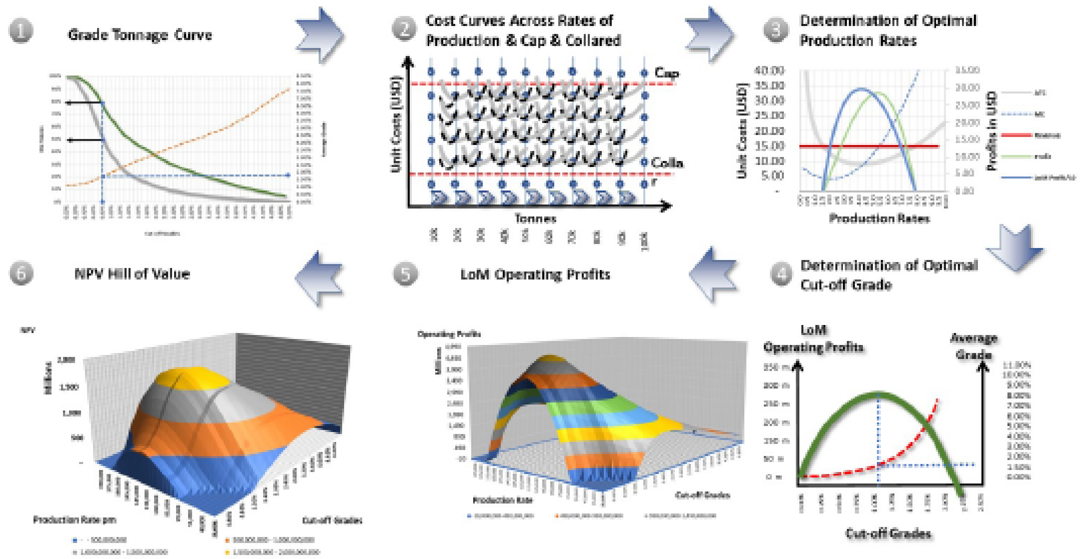

Figure 39: Key Simulation Steps

This information allows mine designers to visualise the viable optimums for NPV, the battery limits for the optimal production rates and the cut-off grades to maximise value or support a maximum contribution strategy.

Capital Intensity and Rate of Capital Expenditure Spend

An additional requirement when modelling ore deposits is to construct a dynamic linkage to the capital intensity required as scale changes, and also to recognise increased construction time to accommodate larger scales of operation. Smaller operations typically have higher capital intensities (measured by $/tonne of ore capacity), but require less time to build, whereas larger-scaled operations require more time to construct but enjoy lower capital intensities. (There are always exceptions to this rule and therefore they have to be modelled.) In the modelling construct presented in this book, capital intensity and construction time reflecting the operation scale is achieved by including a dynamic Capital Intensity Factor Curve shown in Figure 40 and an S-curve shown in Figure 41. For the timing of investment capital to adjust, required capital investment and build time are considered as varying rates of production.

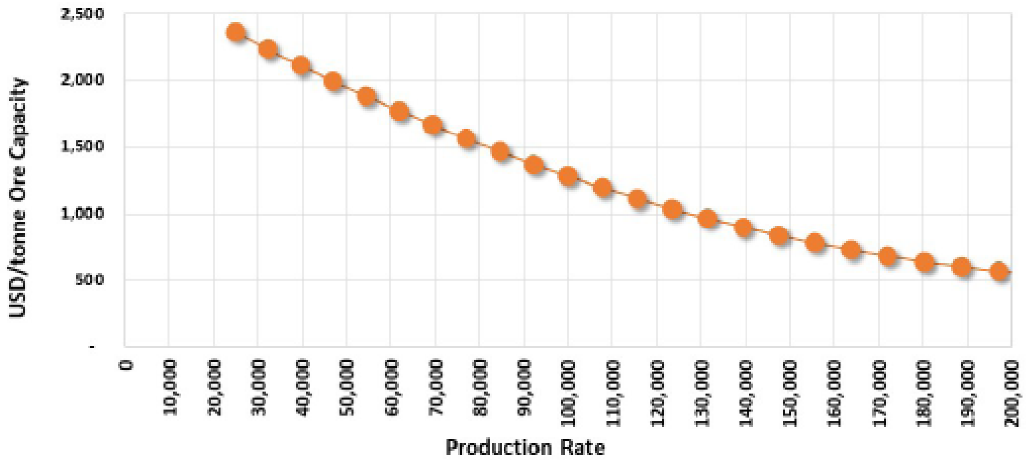

Figure 40: Dynamic S-Curve

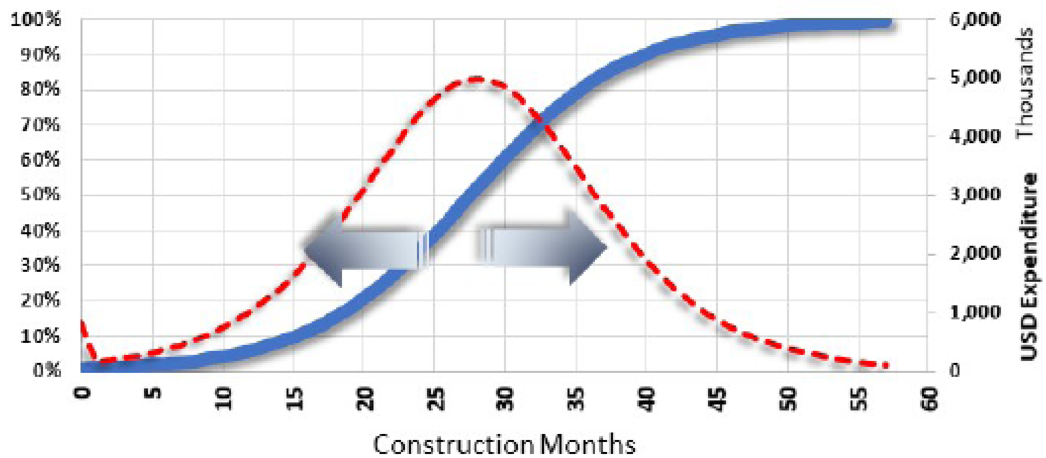

Figure 41: Capital Intensity Factor Curve

The application of these curves affects the payback period for invested capital and by implication, the payback period is simultaneously optimised with the NPV.

At the end of the last commodity cycle, mining companies were heavily criticised for their poor track record of capital allocation. Prioritising volume meant that more capital investment was required to increase scale and the implications of increasing scale necessarily meant that lower mined grades were targeted. The combination of rising costs when optimal economic production rates were exceeded (seen when marginal costs exceeded average costs) and lower mined grades, courted criticism. The fundamental modelling disconnect between an ore deposit and a misunderstanding of economies of scale when modelling mining economics, meant that capital decision-making lacked the benefit of understanding the implications of scale, and criticism followed. Investors demanded “better capital allocation (from) mining companies, to unlock more value from invested capital and (reminded that) the consequences of poor capital allocation decisions include:

● Poor financial returns on capital invested;

● Significant capital write-downs;

● Underperformance in the share price of mining companies, relative to companies in other industries; and

● Destruction of value.”[7]

Provided with a better economic modelling construct and the determination of an ore deposit’s viability ahead of feasibility studies, focuses feasibility studies on maximising NPV constrained by the ore deposit’s capacity to deliver value, and avoiding the temptation of over-capitalising investment and therefore, optimising the capital allocation in a mining portfolio.

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2. (Lane, 2015)
3. (Setting Plant Capacity, 2002)
4. (Setting Plant Capacity, 2002)
5. (Frontiers of usefulness: The economics of exhaustible resources, 2007)
6. (Frontiers of usefulness: The economics of exhaustible resources, 2007)
7. (van der Bijl, et al., 2020)

Chapter 7

The Structure of Costs

“Understand your expenses better than your competition. This is where you can always find the competitive advantage.”

– Sam Walton

Preview

In a nutshell, microeconomics focuses on the Theory of the Firm and what is likely to happen when individual firms make choices in response to changes in incentives, namely market prices and/or methods of production. “As a purely normative science, microeconomics does not try to explain what should happen in a market. Instead, microeconomics only explains what to expect if certain conditions change. If a manufacturer raises the prices of cars, microeconomics says, consumers will tend to buy fewer than before. If a major copper mine collapses in South America, the price of copper will tend to increase, because supply is restricted.”[1]

A complete absence of microeconomic modelling in mining economics exists, and this despite significant academic content that points to its usefulness. While the concepts discussed in these chapters are well known, developing mining models that utilise these insights has had little adoption. It is possible that had concepts been adopted at the beginning of the last commodity super-cycle, the urge to prioritise volume over value may have been undertaken in a more measured way, so as to avoid the devastating consequences of chasing volumes. Microeconomics helps in understanding the drivers of equilibrium, and equilibrium helps to identify optimal trade-offs that the firm must make to maximise economic benefit.

This chapter considers the nature and structure of costs as the precursor to minimising the cost of production and the maximisation of profits. This chapter does not attempt to provide a full exposition of microeconomics, rather it points the reader to the functional concepts used in this book to model cost, assuming a perfectly competitive marketplace. Since the concept of economies of scale has been poorly understood by miners in the past, a short summary of the relevant concepts is provided.

KEY CONCEPTS

- Diminishing Returns and the Structure of Costs
- Economies and Diseconomies of Scale
- Defining Production Battery Limits
- Evidence of these Cost Behaviours in Mining

I. Principles Of Production and Productivity

In the past, miners considered the concept of diseconomies of scale as an improbable reality in the mining industry, rather than convincing themselves that the industry had some special status. The end of the last super-cycle and the global experiment of prioritising volume conclusively debunked that notion. What the experiment showed, is what economists had warned against, that at some point on the production scale, costs stat rising and diseconomies of scale are realised. The over-reliance on accounting measures, in preference to sound economic concepts, has played a significant role in the paradigm that unit costs of production keep reducing as production is increased. While it is true that in the very short run (month on month), fixed cost appears to be high (often in the order of 80%), and not dissimilar to many other industries, but given a longer time horizon (12 months to 60 months) costs are much more variable than accountants care to recognise. Without a fundamental understanding of Production Theory, the underlying reasons for the occurrence of diseconomies of scale will continue to escape the consciousness of the industry.

A mine to produce concentrates or metals that can be sold, generates revenue and profits, and inputs are termed as the factors of production. These factors of production in the most basic form are land, labour, capital and technology. They can be either fixed or variable. Fixed factors are those that do not change as output is increased or decreased, and typically include things like office and factory leases, and capital equipment such as plant, machinery and trucks etc., while variable factors are those that do change with output, such as labour, energy and raw materials. Production requires the combination of both fixed and variable factors to create output. Economic entities like firms and mines need to determine the optimal use of fixed and variable inputs to maximise output. The essence of economic production theory, says that if firms increase the number of variable factors they use, such as labour, while keeping one factor fixed, such as machinery, the extra output or returns from each additional marginal unit of the variable factor must eventually diminish.[2] This concept introduces the idea of diminishing returns.

Diminishing returns can be illustrated to better explain the concept. In Figure 42 (B), labour is considered as the variable factor and represented in the horizontal axis. As labour units are increased, a corresponding rise in output is recorded. The rate of production, however, is not constant and as shown, rises rapidly with the initial contribution of labour, and then slows. A point is eventually reached at which additions of the input yield progressively smaller or diminishing amounts of output. The question arises as to what level of units of labour is optimal for the firm. Two measures are used to assist with solving this problem, the average rate of production and the marginal rate of production.

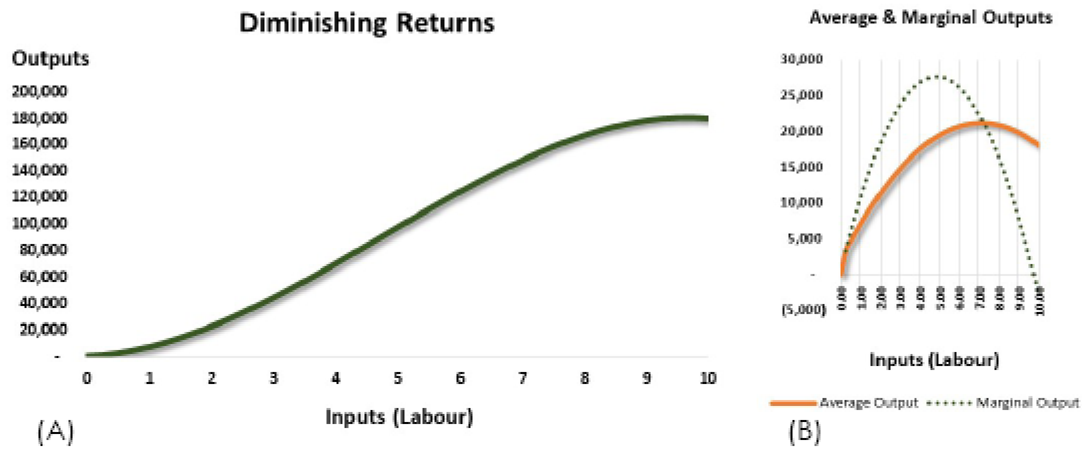


Figure 42: Diminishing Return and Marginal Returns Illustrated

The Average Production rate is mathematically described as:

$$AP = \frac{\textit{Total Output}}{\textit{Total Units of Labour}}$$

Where:

AP = Average Production

Marginal productivity is a term used to describe the output generated by the next unit of labour and mathematically it is defined as:

$$MP = \frac{\Delta \textit{ Change in Output}}{\Delta \textit{ Change in Labour}}$$

Where:

MP = Marginal Productivity

In Figure 42 (B), the above the Average Output (production) is shown by the green line and follows the trend of rising and then falling. The Marginal Production accelerates with the initial increase in labour units and then falls. At the intersection of the Average Production curve and the Marginal Production curve, the optimal use of labour is determined. Every additional unit of labour after this moment yields a lower average unit of output, per labour unit.

Ii. The Nature and Structure of Costs

Variable costs

The diminishing returns curve is used by neoclassical economists to derive the firm's cost curve, which determines the classical economic structure of costs. Since the factors of production come at a cost, the diminishing returns graph can be used to derive the firm's cost curve. The first step in deriving the firm's cost curve is to switch the scales as shown in Figure 43 below. The vertical axis now shows inputs, and the horizontal axis shows the outputs.

The second step is to transform the curve into a cost curve, by multiplying the input costs on the vertical column by a unit rate for the total cost of labour. To demonstrate this, each unit of labour is multiplied by $20 000 and the resulting Figure 44 shows absolute cost for each level of output. This curve describes the variable cost function of a firm or mine derived directly from the production curve.

The cost structure of a firm is incomplete, however, without consideration of a firm's/mine's fixed costs or expenditures.

Fixed costs

Fixed costs refer to costs that do not vary with varying levels of production. Examples of fixed costs for a mining company are overheads, i.e. insurance, equipment leases, land leases, etc., in the many jurisdictions that mines operate in.

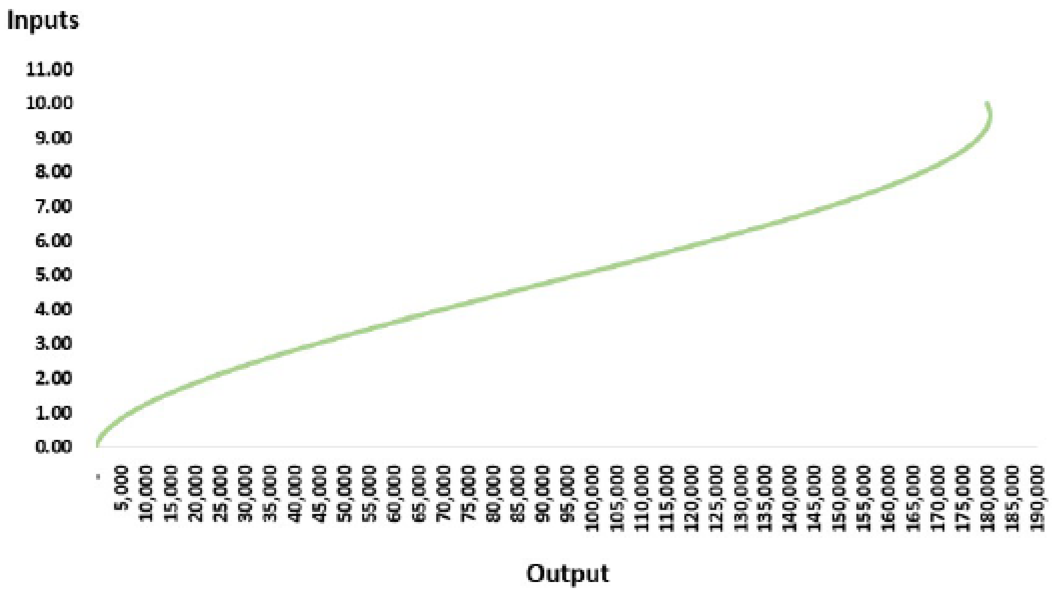


Figure 43: Diminishing Returns Inverted Chart

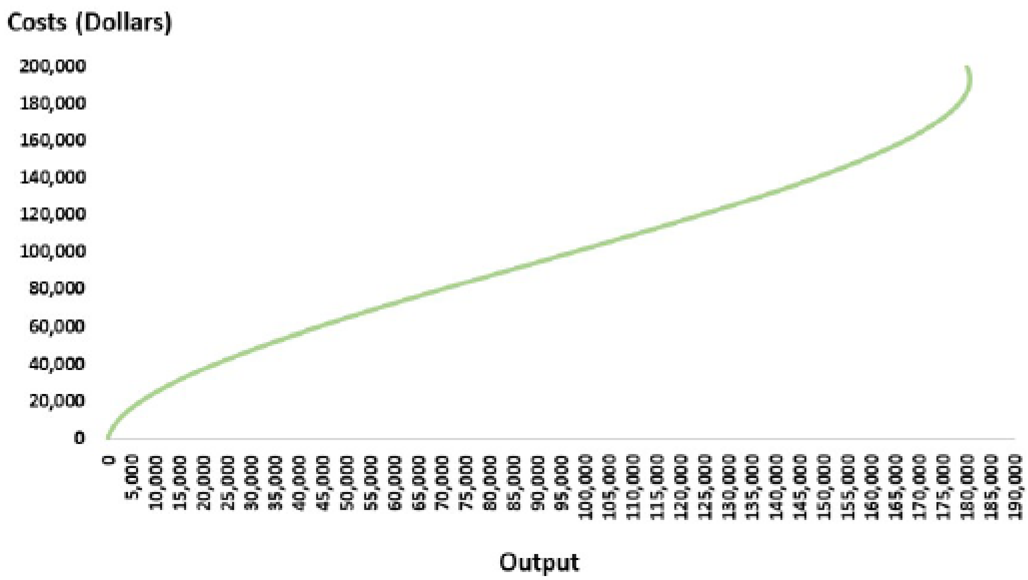


Figure 44: Diminishing Returns Chart Converted to Monetary Value

Power costs often have a fixed and variable component; a fee for the provision of a contracted fixed capacity and a user fee when drawing down power. Water costs can have similar contractual structures in some jurisdictions. Other examples, such as business support costs related to exploration and other production support roles, such as geology, surveying, security, engineering, safety and health, etc., are costs that do not vary with changes in production.

The quantum level of fixed costs is, however, a function of the scale of operations. The larger the scale of operations, the higher quantum of fixed costs. The fixed cost to variable cost ratio can also vary based on management decisions. In the early part of the millennium, it became fashionable for management teams to outsource mining and processing to contract miners. Typically, the cost structure morphed from a characteristically high fixed cost structure to a high variable cost structure, as mining and processing were incurred at the rate of production.

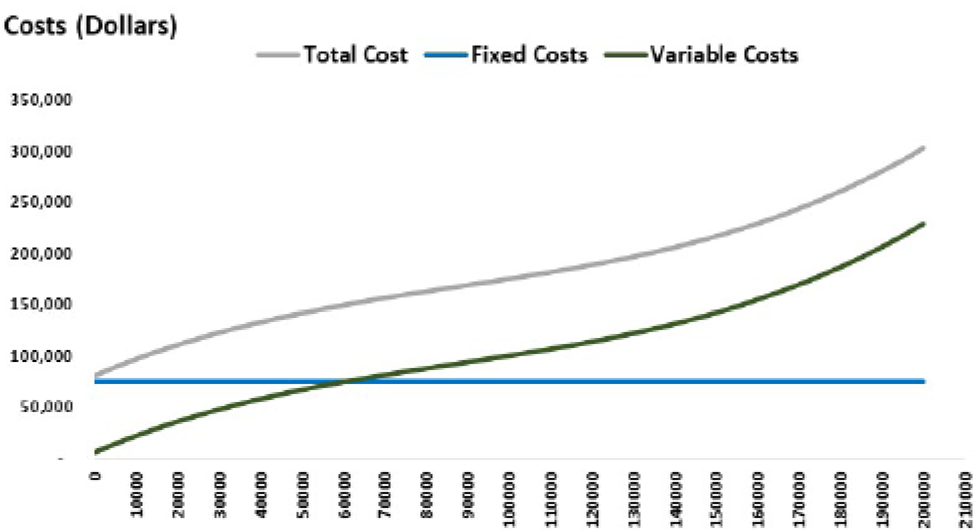


Figure 45: Total Cost Curve Derived

Figure 45, illustrates the Total Cost Function or curve of a firm. The Total Costs are derived by aggregating the fixed and variable costs. In this instance, fixed costs are shown as US$75 000 at the origin, and variable costs as zero. As the rate of production varies (increases) along the horizontal axis, the Total Cost Function mirrors the variable costs, and increases with the addition of fixed costs.

Iii. The Total Cost Function and U-Shaped Cost Curve In CHAPTER 6 the U-shaped cost curve was alluded to as a means to determine the economic battery limits of production. The U-shaped cost curve is derived from the Total Cost Function or curve described above. This

function is mathematically expressed as a polynomial, in the form of: $y=x^3-x^2+x+FC$

Where:

y = Cost in monetary terms

x = Production volume along a production curve FC = Fixed Costs

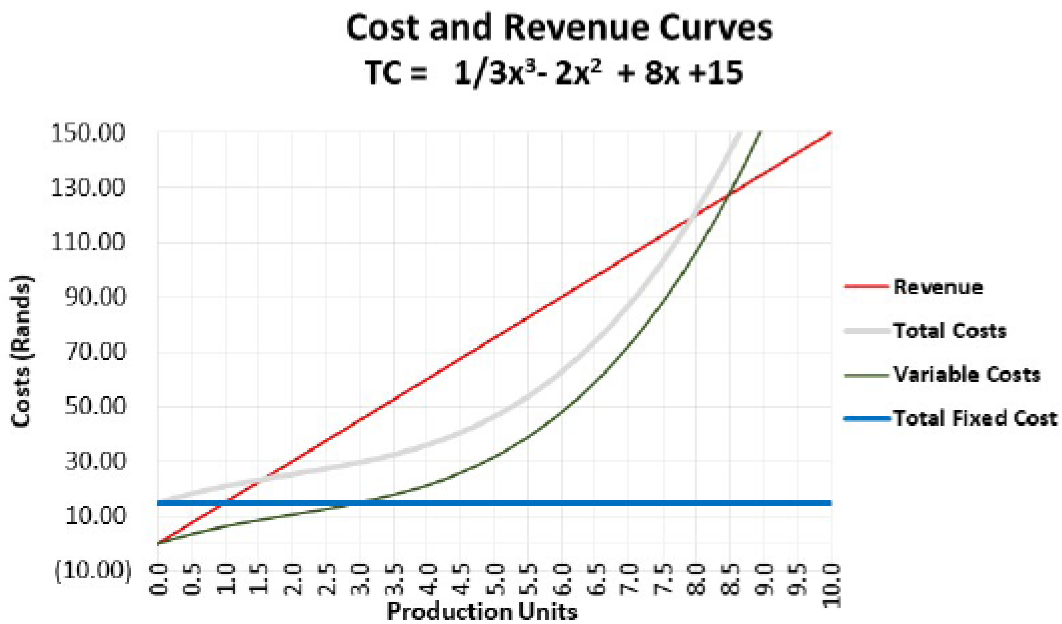


Figure 46: S-Shaped Cost Curve

Using Minnitt's model, the equation can be illustrated in graphical format as shown in Figure 46, above. The equation explains how production costs change at different levels of output, based on the underlying concept of diminishing returns, explained above. Typically, mining accountants have relied upon a more simplistic version of this model, suggesting that variable costs are linear and hence diminishing returns are non-existent. The error in considering a linear variable cost and disregarding the existence of diminishing returns, encourages support for the idea that increasing volumes will attract continuing economies of scale. Examples of embedded diminishing returns in a mine will be discussed after the derivation of the U-shaped cost curve.

Iv. The U-Shaped Cost Curve

The derivation of the unit costs of production is simply done by dividing the costs of production by the rate of production, along a production profile. Each of the cost curves described in Figure 46, has a unit cost equivalent.

Average Total Cost

The average total cost is defined by the following expression: $ATC = \frac{TC}{Q}$

Where:

ATC = Average Total Cost

TC = Total Costs

The behaviour of the ATC initially decreases and then increases with increasing rates and being a function of diminishing returns, related to the variable costs explained above. The shape of the ATC is a U-shaped curve. The minimum point on the ATC curve is represented by the optimal level of production, where the lowest cost of production is achieved.

Average Variable Cost

The average variable cost is defined by the following expression:

$$AVC = \frac{VC}{Q}$$

Where:

AVC = Average Variable Cost

VC = Variable Costs

Q = Production Rate

Its behaviour is like that of the ATC, which initially decreases and then rises as output rises, and it is also U-shaped.

Average Fixed Cost

The average fixed cost is defined by the following expression: $AFC = \frac{FC}{Q}$

Where:

AFC = Average Variable Cost

FC = Variable Costs

Q = Production Rate

As the rate of production increases, the average fixed cost decreases because the same amount of fixed costs are being spread over a larger rate of production.

Marginal Cost

The marginal cost is defined by the following expression: $MC = \frac{\Delta TC}{\Delta Q}$

Where:

MC = Marginal Cost

= Change in Total Costs

= Change in the Production Rate

The MC is the change in total production cost, divided by the change in the rate of production. The MC behaves similarly to the ATC and AVC, initially decreasing and then increasing as the rate of production rises. All the curves described above can be illustrated graphically to show the U-shaped Total Cost curve and the underlying curves. Figure 47 illustrates this.

Figure 47: U-Shaped Costs Curve

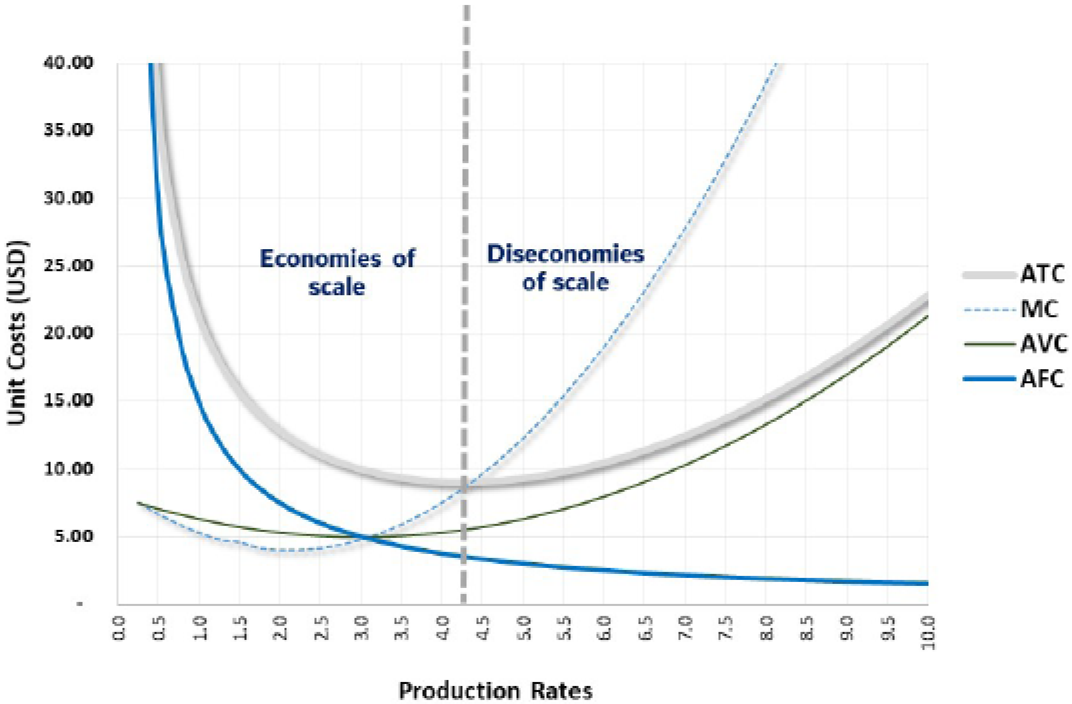


Figure 47: U-Shaped Costs Curve

Shown is the character of the ATC under the constraint of diminishing returns. ATC can be seen to fall initially and then at the point when diminishing returns begin to turn negative, unit costs begin to rise. The significant fall in the ATC is related to the fixed costs initially, but variable costs while falling initially, start to rise and hence the impact on diminishing returns is felt on variable costs, and not on the fixed cost of production. Hence the AFC continues to decline, first rapidly and then more slowly, while the AVC falls more slowly initially, and then begins to rise as shown.

The marginal cost, or the cost of the next unit of production, initially falls and then rises rapidly to intersect the ATC at the point where diminishing returns turn negative. The definition of this moment is important, as it describes the transition from the cost benefits of economies of scale, to the cost disadvantages of diseconomies of scale. Rising unit costs after the moment implies that profitability shrinks thereafter.

The general rule in microeconomics is that the optimum production rate is achieved when the marginal cost intersects the marginal revenue. The divergence to this rule has been dealt with in the last chapter, save to repeat that for a depleting resource with a defined life, the profit maximising moment for the Life of Mine is where costs are at a minimum. The optimal profit per annum is the point at which the marginal revenue and the marginal cost intersect. These two production moments provide tactical battery limits to adjust to factors such as price movements, grade variations or recovery issues, in the short run.

Bringing the two graphs together for comparative purposes is useful to demonstrate the optimal moments on the Total Cost Function for a firm and its unit cost derivative, i.e., the U-shaped cost curve. When individual cost curves are added to others within the industry, an aggregate industry cost curve results. Aggregate cost curves are used widely in the mining industry and are referred to as the industry cost curve. More attention will be paid to this in the next chapter, but highlighting the micro moments, apply equally on an industry scale, save for the absence of fixed costs seen in Figure 48.

- Points 1 and 2 in frame B are the breakeven levels of production. They correspond to the points in frame A, where the total revenue curve (TR) intersects the total cost curve (TC). Production above and below these points will result in economic losses and they are therefore the breakeven points.

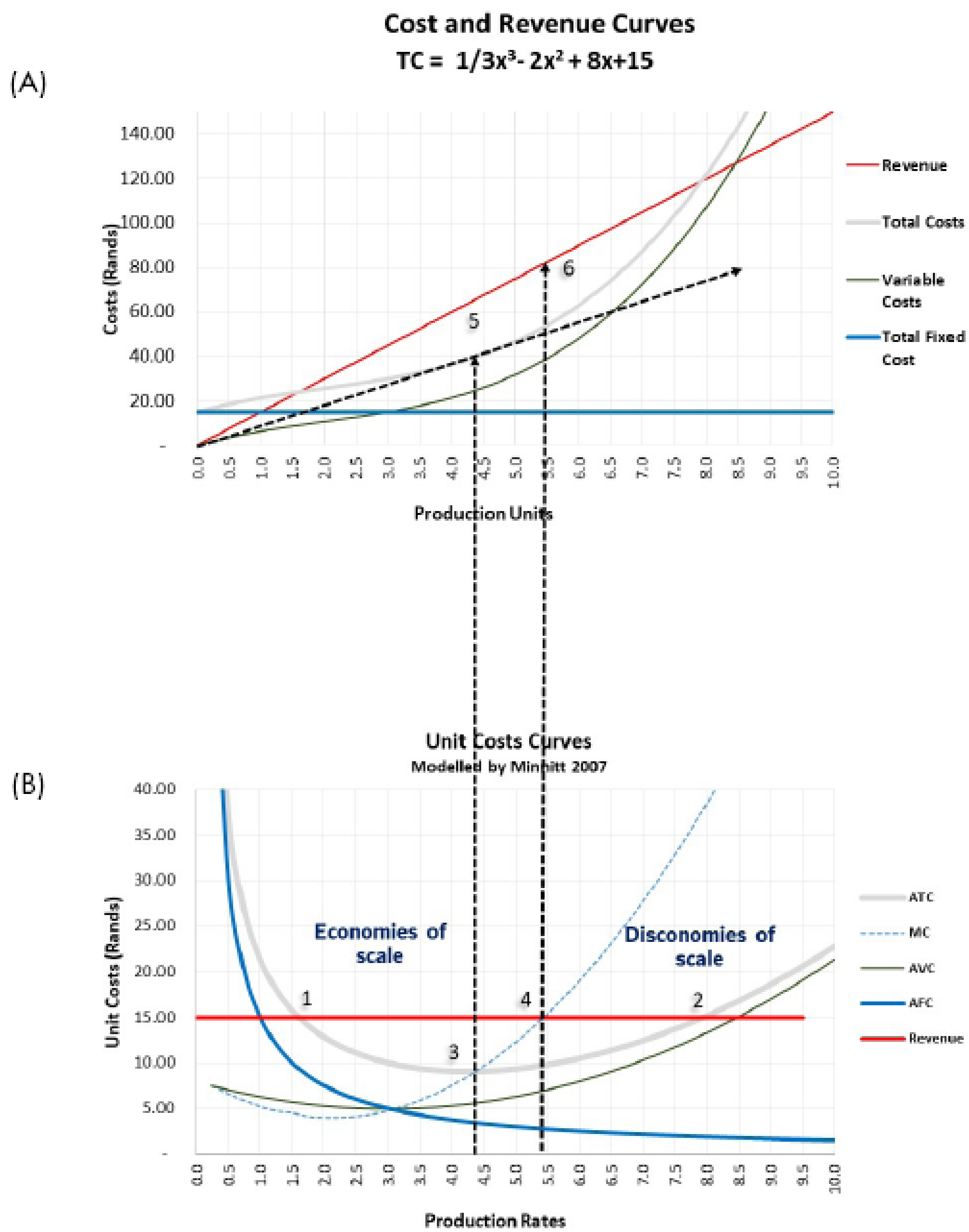


Figure 48: U-Shaped Cost Curve and S-Shaped Curve Coincident Moments

- Point 3 is the minimum point on the ATC and is coincident with the MC bisecting it. This is the Life of Mine optimum level of production, described by Minnitt. It is also the point that describes the division between economies and diseconomies of scale. Beyond this point, the average unit costs of production begin to rise. This point corresponds to point 5 in frame

A and a useful point of incidence when considering aggregate demand, the industry cost curve and price discovery.

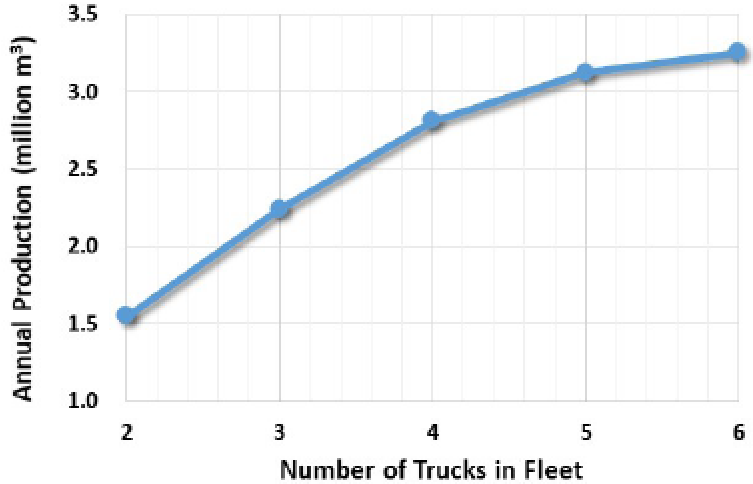
- Point 4 is the intersection between the marginal cost (MC) and marginal revenue (MR) curves at which MC = MR. At this level of production, the slope of the total revenue curve (TR) is parallel to the total cost (TC) curve in frame A. This rate of production maximises net revenue (TR – TC) per year.

V. Example of Operating Mine Costs

Evidence of diminishing returns in a mining operation is provided by Ian Runge: Mining Economics and Strategy. In Chapter 9, a case study is presented that involves a mine expansion with additional waste removal of approximately 3 million m^3/ annum. Of relevance to this subject matter, is Runge's calculation of operating costs for fleet equipment. The study investigated the optimum fleet size to minimise the unit costs of production. For the typical haul cycles, estimated annual production for 126 truck capacity was undertaken. The results of this were summarised and presented in this case in Figure 49.

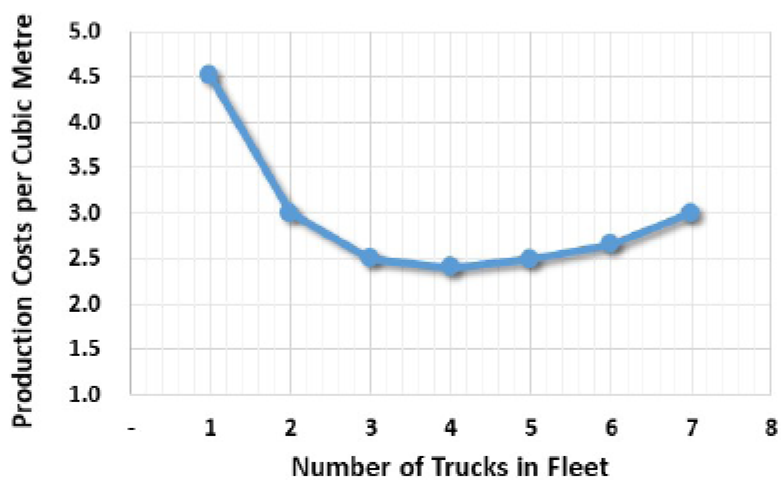
Practically, Runge states, "That no one fixed number of trucks matches the mine's requirement exactly, since the mine schedule does not necessarily demand an exact match. If an optimum fleet turns out to have a production slightly more or less than the annual 3 million m^3/ annum, the other equipment can be scheduled to make up the difference."[3]

Since different equipment lasts for different amounts of time, depending on type and schedule of use, the evaluation was undertaken using all capital costs and operating costs, noting that before purchases, all these costs are completely variable.



Source, Runge 1998

Figure 49: Annual Fleet Production



Source, Runge 1998

Figure 50: Fleet Average Costs of Production

The discounted average cost of production was calculated for each of the options in this case, and the assumed fleet consisted of loaders and trucks. The results of these calculations are shown in Figure 50.

Runge points out that a superficial assessment could easily recommend a fleet of four trucks, for which annual production is slightly less than required. The difficulty of the conclusion to buy four trucks is that it focuses on average costs, to the exclusion of marginal costs.

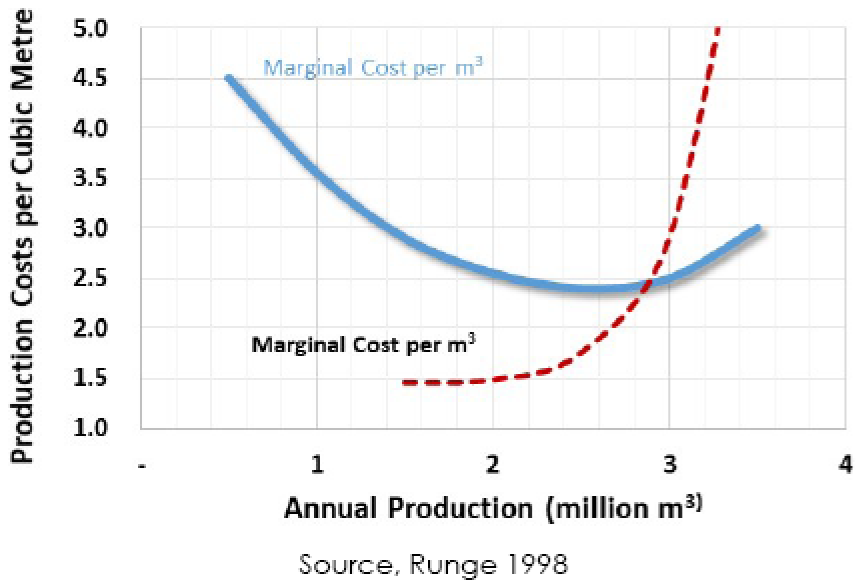


Figure 51: Average Costs & Marginal Costs Relative to Annual Fleet Production

Alternatively, a fleet of five trucks is viable, with production slightly more than required. Runge shows that this can be solved by considering the marginal costing of production, to determine the optimal number of trucks in a fleet. To do this, the annual production is compared to the production cost per m^3. Figure 51, shows the plot of average costs and marginal costs, relative to annual production rates. The production cost curve shows that the marginal cost of production rises exponentially faster before the 3 million m^3/annum hurdle. Runge then concludes that four-fleet truck fleets are preferable to the five-fleet truck fleets, because the marginal cost of moving material by the fifth truck is substantially higher. The optimal fleet capacity is therefore 2.8 million m^3/annum for an owner/operator solution. Runge recommends that if additional production is required, a contractor should be used.

Vi. Time Periods for the Firm

The structure of costs is related to the time function. Economists argue that in the long run, all costs are variable, as management can decide on the changing factors of production simultaneously to optimise the business. An explanation of the time horizons is considered below.

→ The very short run

The very short run time frame is characterised by production, and it increases limitations to using up existing stocks of inputs.

→ The short run

The short run time frame is characterised when increased output is related to using more variable factors such as by hiring more workers but not increasing the fixed factors. In the short run, firms do not use extra fixed factors such as moving to new premises, to increase output. Therefore, in the short run, at least one factor of production is fixed.

→ The long run

A firm enters a long run time frame when it increases its scale of operations. Increasing scale means that no factor of production is fixed, and all are variable. A mine expands by increasing its mining rate, by increasing its fleet size and/or its plant processing capacity, and employing more workers. Typically, this requires an injection of capital.

→ The very long run

A whole industry enters the very long run when there is a significant change in the use of technology. For example, the adoption of artificial intelligence, drones, etc.

For the purposes of optimising the optimal rates of production, the methodology of this book is to test a sequence of short run cost curves by dynamically changing the total cost structures through the production range. The approach embeds the idea that in the long run, all costs are variable, but simultaneously recognises that at a point on the cost curve, short run economics prevails. Simulating all possible cost structures at each point recognises both the short run and the long run cost dynamics, and offers the determination of the optimal cost structure for a specific ore deposit.

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1. (Investopedia, 2019)

2. (Economics Online, 2020)

3. (Runge, 1998)

Chapter 8

Supply and Demand Dynamics

“We’ve always been wanting to keep building and keep putting the cash which we generate into new assets. That’s what we’ve got to stop doing as a mining industry. We’ve got to learn about demand and supply.”

– Ivan Glasenberg

Metal price equilibrium is a function of supply and demand in a competitive free market. This chapter describes elementary concepts of market equilibrium pricing as a function of supply and demand. The microeconomic subject matter is broader, but it is not the intent to replicate microeconomic theory in this chapter, rather, the relevant if not basic ideas for the theory of price discovery in a competitive market is described, to lend support the theme of this book.

The aggregate supply and aggregate demand in a completely competitive economy is the mechanism that determines the price of goods. Aggregate supply is a function of the cumulative cost curves of individual mines, which are commonly represented in the mining industry as “Industry Cost Curves”. The relationship between the Total Cost Function and the U-shaped cost curve at an industry level provides a mechanism for understanding price equilibrium, driven by market forces. Aggregate supply curves can provide useful insights into the behaviour of long-term metals price trends being a requirement for microeconomic modelling, mineral resourcing and ore reserving.

For perfectly competitive markets, economic equilibrium is achieved when the price demanded by consumers is the same as that required by producers. Since mine modelling requires a view on the long-term metals price, and forecasting methods have proven to be disappointing, the industry cost curve is an alternative approach for adopting a long-term metals price. An appreciation of an industry’s cost curves composition and related time frame is essential if reasonable judgements about future market equilibrium pricing are to be made.The strength of the cost curve approach to long-term price forecasts is that it is grounded in supply and demand concepts and is therefore rationally more robust than stochastic theories of mean reversion and other time-variable approaches.

KEY CONCEPTS

- The Short Theory of Supply and Demand
- Aggregate Supply and the Industry Cost Curve
- Long-term Price Discovery Methodology

I. The Basics of Supply and Demand

Rising prices are fundamentally the indicator for miners to expand production to meet a higher level of aggregate demand, as was the case during the super-cycle. On an elementary level, when demand increases amid constant supply, consumers compete for the goods available, driving prices higher. This dynamic between supply and demand incentivises mines to increase output in order to sell more product. The resulting supply increase causes prices to normalise and output to remain elevated. This book assumes a basic knowledge of first year microeconomics, but for the sake of completeness, some basic concepts are summarised with regard to price discovery and the application of Industry Cost Curves.

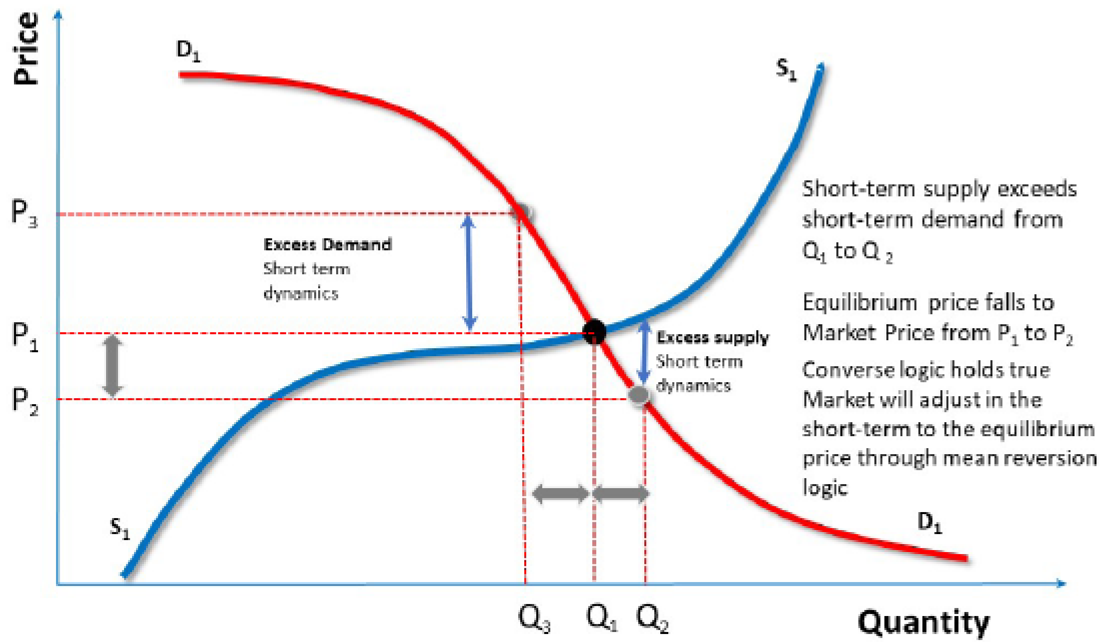


Figure 52: Supply and Demand Curves – Price Equilibrium Under Normal Market Conditions

Figure 52 shows the basic supply and demand curves discussed in a microeconmic textbook. The essense of this illustration is to describe how price is affected by supply and demand factors. The vertical axis shows prices, while the horizontal line shows quantities of a product. The red line is the chracteritic curve for demand, while the supply curve is characterised by the blue curve. P1 is defined as the equilibrium price, the price at which the market supply and demand needs are perfectly balanced. The market attempts to maintain this price equilibrium. However, many factors influence the perfect stability of this price as short-term supply and demand encounter mismatch.

When short-term supply exceeds short-term demand, namely the quantity of a product, Q1, moves to Q2, then as the graph indicates, the price the market will be willing to pay moves from P1 to P2. Conversely, if the product is temporarily in short supply, supply moves from Q1 to Q3, and the price will follow this supply deficit by moving from P1 to P3 to achieve this. This is because competitors will compete for the product by increasing the price. They are prepared to pay for the product in order to secure supply ahead of other competitors of the product. This explains the basic supply and demand dynamic in a perfectly competitive market. In a perfectly competitive market, suppliers are said to be price takers, and the presence of thousands of buyers determines the market price at any point in time, based on short-term supply and demand dynamics.

Another dynamic occurs when there is a structural shift in the market, where a long-term decline in demand, for example, the switch away from the use of fossil fuels, is causing demand to decline. On the other hand, the switch to “green” commodities such as copper, nickel, manganese and lithium, among others, is causing a structural change in the demand for these metals. Microeconomics refers to these changes as overall shifts in supply and demand.

During the last commodity super-cycle (and now being revisited in 2021), the mining industry experienced an increased overall demand for commodities. Overall demand causes the demand curve to shift to the right (D1 D1 to D2 D2). This can be illustrated and shown in Figure 53. The change to overall demand is seen by the increase in demand of product Q1, to move permanently to Q2 and a resulting change to price. The initial market imbalance requires price discovery in a perfectly competitive market. The market, through this process, sets the new equilibrium price, being set at P2. The converse to this is that overall demand falls for products from Q1 to Q3 and the demand curve shifts to the left, with price falling from P1 to P3.

Shifts in structural supply are similar. If overall supply increases, prices fall and if overall supply decreases, prices will rise. The elasticity of supply and demand is beyond a simple discussion of supply and demand dynamics, save to say that the slope of the curve defines what is termed the elasticity of demand and supply. In the extreme case, the supply curve is defined by a vertical curve, which means that supply does not vary with price, while on the other extreme, supply is indicated by the horizontal curve, implying that price is not affected by supply. Again, the same rationale can be applied to elasticities of demand. In reality, all of these dynamics are playing out daily and as structural changes occur to supply and demand, elasticities of supply and demand change too.

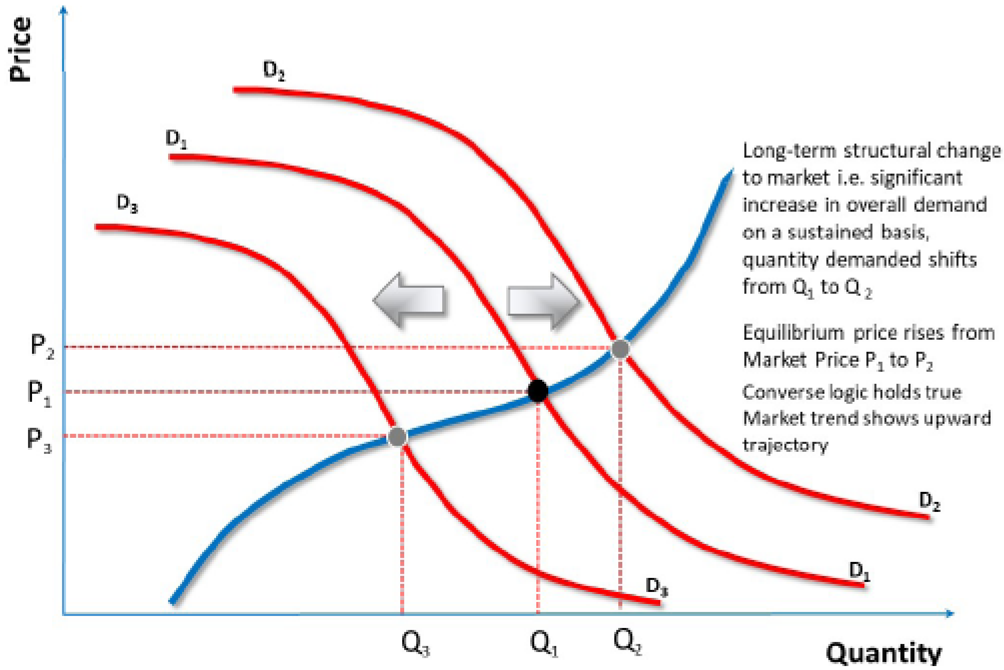


Figure 53: Shifts in Overall Demand and Supply

The basic lesson is that if miners chase volumes and projects, supply at some point becomes inelastic and the sustained "bust" period output ensues, as the project pipeline causes the supply curve to flatten and become relatively inelastic to demand. This nuance is possibly the reason that Ivan Glasenberg called on miners to learn about supply and demand fundamentals, to ensure that the industry does not see the extremes of boom-and-bust years of the early millennium. Ultimately, the nature of the business is dependent on the discovery of metals in the ground, and this predetermines long lead times to supply the market. In order to have long-term supply, miners required the necessary long-term price incentive to commit funds to exploration and mine development. On the other hand, miners need to fully understand the microeconomics of the ore deposits that they manage, in order to ensure that the temptation of prioritising volumes over value creation does not result in the industry revisiting the past.

Ii. Aggregate Supply and Industry Cost Curve

Aggregate supply is defined as the total production of an industry and, in the case of mining, copper, lead, zinc, gold, platinum, etc., over a given period. Miners make decisions about what quantity to supply, based on the profits they expect to earn. Profits, in turn, are determined by the price of the outputs the mine sells and by the price of the inputs, like labour or raw materials that the miner needs to buy. In a competitive market, price or equilibrium price, as described above, determines the quantity and/or output for a mine. Mine 2 will produce at a different rate of production, with a different cost structure, as will firms 3, 4, 5 and so on, as determined by each firm's marginal costs. The total quantity that the industry will produce at a given price will be the sum of the individual quantities that all firms supply at that price. The aggregate supply can be illustrated as follows:

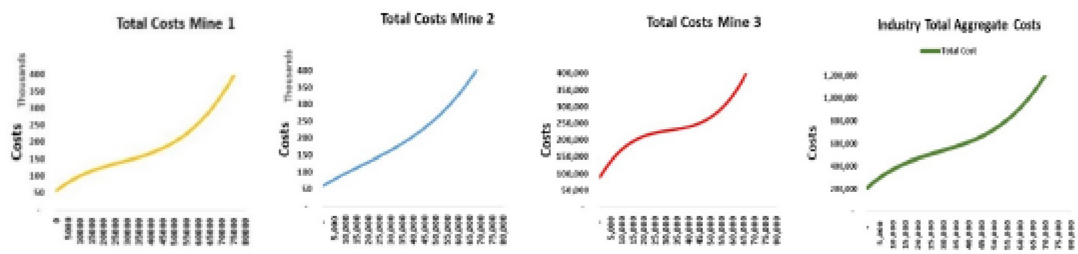
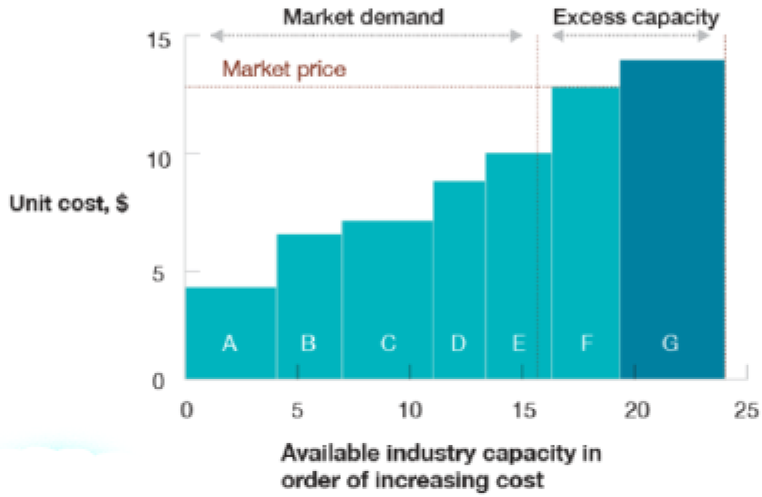


Figure 54: Aggregate Supply Curve Based on Individual Mine Output

Miners' ability to influence the aggregate production level is limited, as multiple competitors act independently in a perfectly competitive market. Companies try to achieve positions along the industry cost curve, in the lower quartiles of the aggregate supply curve, to immunise an operation against adverse market price movements.

McKinsey & Company (McKinsey) claims the honours for the development of the industry cost curve. The supply demand relationships that underpin the cost curve framework as an analytical tool have been well understood for a long time. McKinsey says its "contribution has been to bring discipline and a practical set of definitions, and by weaving this tool into the decisions facing management teams in general, like pricing decisions, capacity decisions and strategy decisions, including mergers and acquisitions." Their formulation of industry the curve, Figure 55 illustrated below, shows the relationship between capacity and cost, by arranging the cheapest capacity to the most expensive and serving a given market. McKinsey offers their explanation on the formulation and application as follows:



Source: McKinsey & Company , McKinsey Industry Curve

Figure 55: Mckinsey's Industry Cost Curve

"On cost side, unit cash costs are used rather than accounting costs that use depreciation and other non-cash cost items. Cash costs are the focus because the power of the cost curve focuses on the marginal producer, and when they receive enough marginal revenue to cover their out-of-pocket production costs or when they choose to exit, which is when the reverse is true. The relevant costs McKinsey & Company consider in their curve are: cash costs, transportation costs, working capital, and the cost of capital that is tied up in fixed and working capital, associated with the new capacity. If a producer is considering taking capacity off-line, closure cost is included. McKinsey states that the industry cost curve so formulated, is simply another representation of the classical microeconomic U-shaped cost, showing elasticity of demand. Once the costs have been arranged from lowest to highest, the next step is to identify the market demand level and place it on the curve, against the capacity that is available. The market demand line is represented as a vertical line, representing the market demand known at a point in time. The industry capacity to the left of the demand line is the most efficient capacity to meet the demand level, and the capacity to the right, represents the excess capacity or unneeded capacity to meet demand. The market price will be bracketed, in an equilibrium manner, between the supply unit where the demand line is going straight across, to the left, and the first unit of unneeded capacity in the market."

McKinsey also suggests that the tool can be used in a predictive manner, but that caution must be taken when applied in a predictive way, to consider that uncertainty is introduced, leading to an uncertain range around price. The cost curve, from their perspective, is ideally suited for commodities, and fundamental in analysing the dynamics of pricing. By bringing greater microeconomic rigour to strategy formulation, mining companies can benefit from the insights relating to the market's predicted price and profit sensitivities, notwithstanding their competitors' actions. In principle, the industry cost curve allows companies to predict the impact of industry capacity, shifts in demand, and the influence that input costs have on market prices.[1]

McKinsey's cost curve has been widely adopted by the mining industry across a range of commodities, and the Holy Grail for miners is said to be a cost position within the first quartile of costs. Whilst these now standard curves are useful in measuring the relative competitive cost positions of miners, the construction of the S-shaped and U-shaped cost curves affords mining companies greater application and insights to optimise and maximise their extraction strategies and the core subject matter of this book. Mine costing is, however, more complex than non-mining producers and requires greater rigour. A significant complexity is understanding that mining costs are largely driven by the quantities of ore mined and milled, rather than the metals produced. The significance of this is that in the world of mining, low-cost producers may report as relatively higher cost producers on the metal produced cost curve, if they do not benefit from either high-grade orebodies and/or non-high-grade by-product production. The industry cost curve widely used by investors and the industry largely disguises the costs of production, as higher-grade ore deposits or by-products minimise the cost of production. The risk is that management teams of well-endowed mineral deposits can operate less efficiently than their competitors, yet still maintain their competitive industry positioning. The application of microeconomic rigour is to cut through this noise and highlight an ore deposit's inherent economic capacity and cost structure, based on the underlying cost drivers.

Nevertheless, however inefficient or efficient and/or well-endowed or poorly endowed an orebody being mined; the industry cost curve remains an important and useful market benchmark. For market analysts and investors, it provides relative market insight, into which mines and/or miners are most vulnerable, to price movement at varying price levels. For example, Figure 56 shows that miners producing at costs above the spot price ($/Tonne 6 000), the red, are loss-making, and will not be able to sustain profitability if the metal price is at equilibrium at $/tonne 6 000. As a benchmark, it can also indicate the floor for the metal prices. An industry cost curve, being the same as the aggregate demand curve, and derived using C(1) costs, provides the bare minimum economic costs incurred by a miner. When price shocks occur, the industry can sustain price levels on this cost curve for a limited period, before supply and demand pressures for a new price discovery.

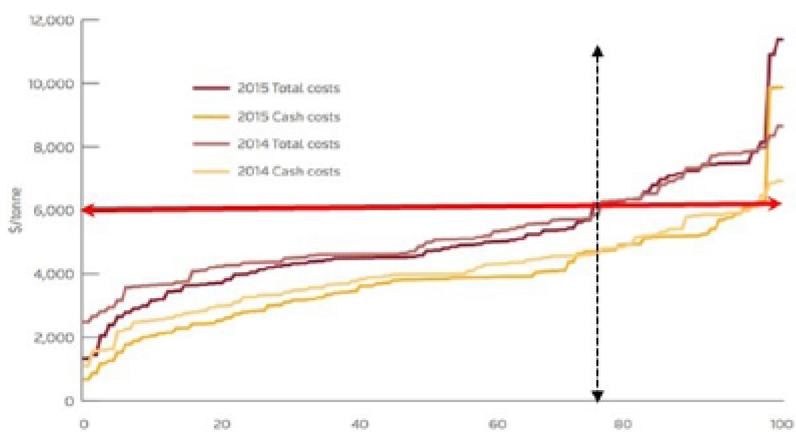


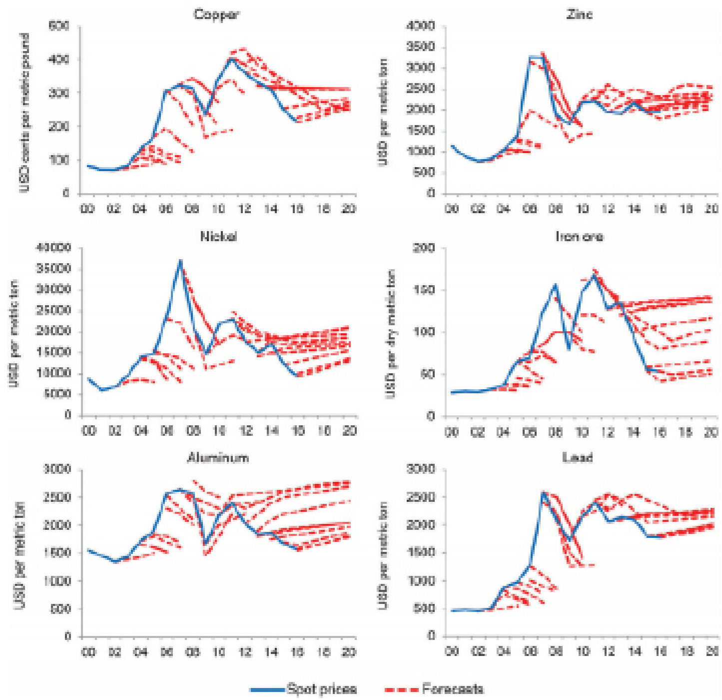
Figure 56: miners producing at costs above the spot price

Iii. Metal And Commodity Price Forecasting

Fornero and Kircher (2018), succinctly defined the challenge: "The rise of the [copper] spot price in the mid-2000s, was not validated by higher forecasted prices on a medium to long-term horizon. Instead, it was considered as a transitory price increase, by the professional forecasters, who predicted that the spot price would return to values of around 100 cents. Due to the crisis (Global Financial Crisis), the price fell and almost reversed the rise from 2003 to 2007, reaching a minimum of approximately 140 cents (where the annual average understates somewhat the dynamic evolution of the spot price). That decline was relatively short-lived, and after the crisis, the copper price quickly recovered and exceeded its pre-crisis levels.

However, the higher post-crisis prices were also accompanied by higher forecasted prices, as part of a process of gradual forecast revisions, which had already started around 2007. In the following years, the forecasted prices reached values much closer to the effective spot price. Hence, the professional forecasters seem to have incorporated a more persistent price increase in their forecasts over time. More recently, as the commodity cycle has turned and prices have fallen, it has taken the forecasters again, several years, to adjust their expectations on future prices downwards."[2] In short, forecasters got it wrong and lagged the price trajectory.

This has material implications for strategic management, let alone accounting and balance sheet implications, when prices fall. The poor forecasting capability of these experts also got it wrong for all other commodities forecasted in the study that Fornero and Kircher conducted, Figure 567.



Source: Spot Prices of various Commodities from 2000 through 2016, versus World Bank Forecasts. Fornero & Kircher (2018)

Figure 57: Commodity Price Forecasting Track Record

The observation for the metal price forecasting has been independently invalidated by many, including SRK, an international mining consulting firm, and other subject matter experts. Despite this, the mining industry continues to rely on these forecasts in the absence of a better or more robust alternative. The lack of an alternative convention fanned the unbridled imposition of impairment charges at the end of the last super-cycle,that resulted in significant shareholder loss and reinforced the industry's reputation as a boom-bust bet.

During the last super-cycle, when metals prices were accelerating, metal price forecasters cited mean reversion as the overriding hypothesis for forecasting long-term metal prices. At the end of the super-cycle, this hypothesis was abandoned in favour of panic. The mean reversion hypothesis, when prices crashed, was not followed. Simply, mean reversion implies that when prices rise above the mean, prices will revert to the historical mean (average) price, and vice versa that when prices fall, they too will correct back to the historical mean price. The key challenge, however, is that the historical mean is undefined.

In the absence of this, the industry has experimented with a number of different approaches. Conventional wisdom is to choose a methodology described below:

● Long-term historical averages;

● Three-year moving averages;

● The lesser of the three - year moving average and current spot price – after the US Securities and Exchange Commission (SEC);

● Consensus prices;

● Contract pricing;

● Margin over cost of production;

● Current spot commodity price; and

● Specialist consultant reports.

These methodologies largely result in short-term price forecasts or are subject to extreme conservatism, which is problematic for mineral resourcing, ore reserving and viability studies, if not for accounting practices that seek to impair balance sheets. There remains no clear consensus as to determining what the long-term mean price is and how to derive it. This chapter will offer a simple methodology, based on a time weighted historical average.

Iv. Mean Reversion Versus Trend Tracking

The hypothesis of mean reversion emanates from equity trading. Mean reversion and trend tracking are two concepts that are used in technical analysis. Mean reversion is the idea that markets tend to swing around some mean price. When it moves above this mean, it is considered over-bought, and conversely when it moves below the mean price, it is considered over-sold, shown in Figure 58. The mean price is left to the trader to decide and is typically a moving average of variable duration, to allow the trader to take a contrarian market position, to profit their reversion to the mean. Trend tracking considers the price direction and momentum. Trend tracking assumes that the market trend is a function of price inertia, whereas mean reversion considers price inertia as a pending signal for price correction. These concepts form the basis of modern technical analysis, which has resulted in a plethora of statistical formulations to predict the timing of buying and selling a stock. Trend tracking is used to establish a long run price trajectory, while mean reversion is used to signal price correction when prices significantly exceed the trending mean.

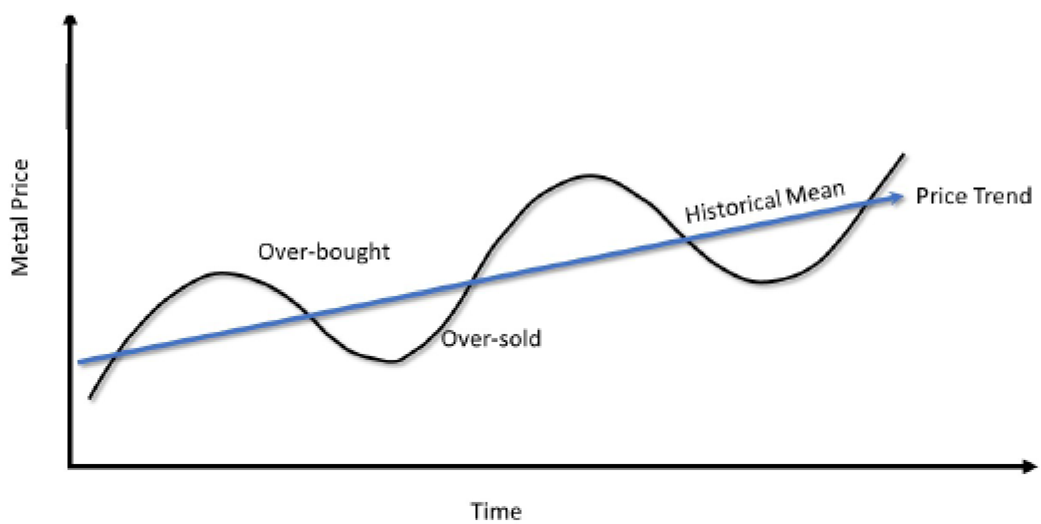


Figure 58: Mean Reversion and Price Trend

V. Determining a Long-Term Price Line

The metal price is the single most significant variable when modelling the NPV of a mining project. The metal price assumption is a variable that is not only significant for economic modelling, but also for defining the economic boundaries of mineral resources and ore reserves; the mining inventory. The difficulty has been that price assumptions used in these metal price assumptions suffer point and cyclical volatility, which means that price is uncertain and therefore not predictable. The tradition of metal price forecasters has been to mean revert prices to a recent low when prices are rising, and then assume that any correction or cycle downswing is indicative of the price reverting to the mean. The mean used is not explicit and there is not general consensus as to what the long-term mean is for prices to revert to. The brave adjust their long-term prices upwards when commodity prices rise and see their mining inventories rise, because cut-off grades can be adjusted downwards. When prices fall, as seen in the last super-cycle, the conventional wisdom is to run mining inventories at arbitrarily lower prices and impair the mining inventory. The wealth destruction that occurs as a consequence of this behaviour means that the industry perpetually suffers from the label that it is a boom-bust industry.

The reality is that the mining inventory is an in situ stock that remains intact, despite the vagaries of market economics. The question is simply as to the timing of when that in situ inventory can be economically extracted. An ore deposit's depletion life is typically between 15 and 30 years, while some deposits yield depletion lives in excess of 50 years. The metal price assumed for economic modelling therefore needs to consider an indicative long-term trajectory which takes cognizance of multiple cycles. Guessing the length and depth of cycles is as difficult as guessing prices, despite complex forecasting mathematical methodologies that have disappointed the industry. What is proposed is not another sophisticated mathematical formulation, but a sensible convention that yields a stable mean trend which can be defended with the necessary simplicity and transparency.

Historical mean trending and mean reversion, combined with historical cost profiling, offers an alternative approach that yields a more stable long-term perspective of where metal prices will likely trend, on the assumption of historical long-term momentum. Considering the time-weighed historical average and forward momentum, long-term mean metal prices can be determined against which mean reversion of price oscillation can be measured. Superimposing cost halos offers trigger moments for mean reversion. This provides a sensible basis for decision-makers to consider the cost collar for metal prices below which production becomes unprofitable, and mines start to endure financial pressure, leading to closure. These cost tramlines should also serve to provide a more measured response to the knee-jerk reaction resulting in balance sheet impairment when metals prices correct, and a rational argument to indicate mean reversion back to market equilibrium prices.

Determining the marginal industry cost moment relies on the microeconomic logic outlined in the previous chapter and with specific reference to Figure 48. A sloped line, tangential to inflection point, marked on Figure 59, indicates the industry excess capacity moment, defined in McKinsey’s construct above. Plotting key cost definitions for aggregate supply, i.e. cash costs, all in Sustaining Costs and Total Costs, shown in Figure 60, creates a price equilibrium bandwidth; these moments can be plotted against historical prices to show how spot prices behave in relation to the costs of production. The historical equilibrium price moments in relation to historical cost moments is illustrated in Figure 61, revealing market sensitivity to price setting the equilibrium moment.

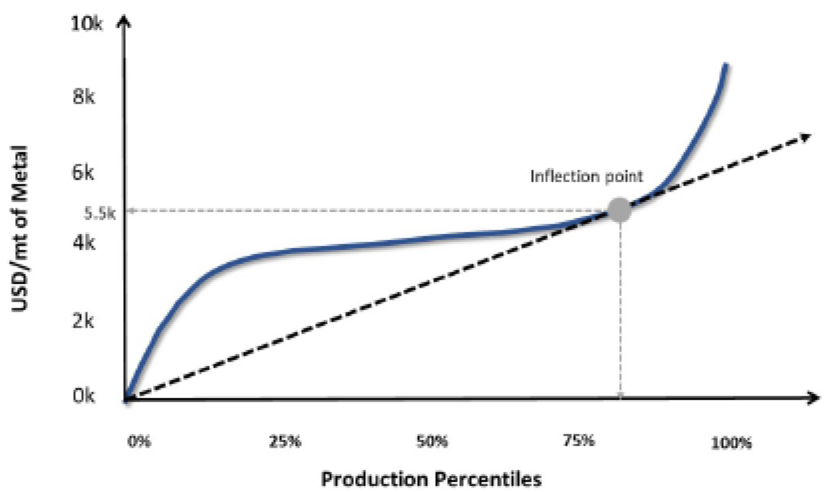


Figure 59: Industry Cost Curve And Excess Demand Determination

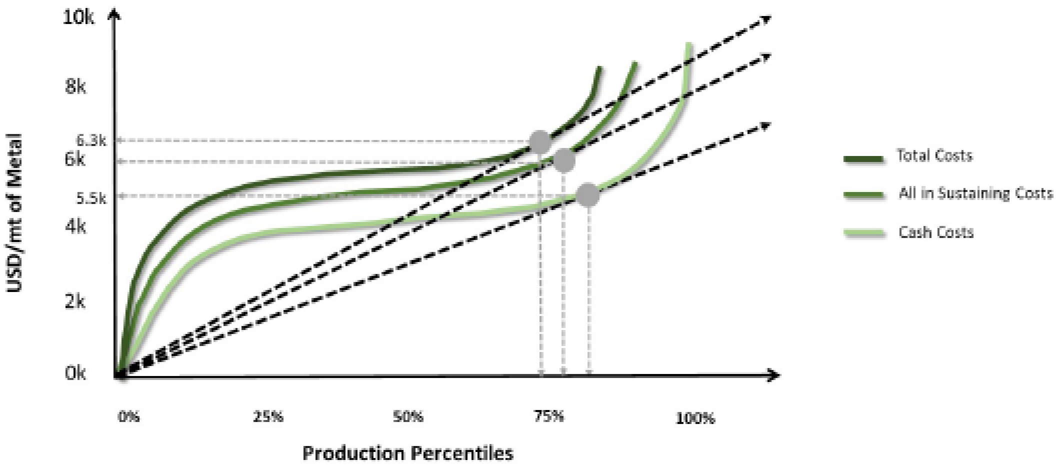


Figure 60: Mining Industry Cost Curve Definitions

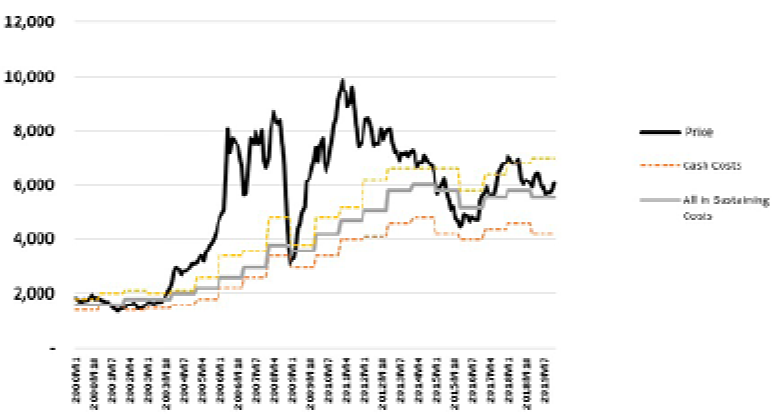


Figure 61: Historical Cost Profiles Versus Historical Copper Prices

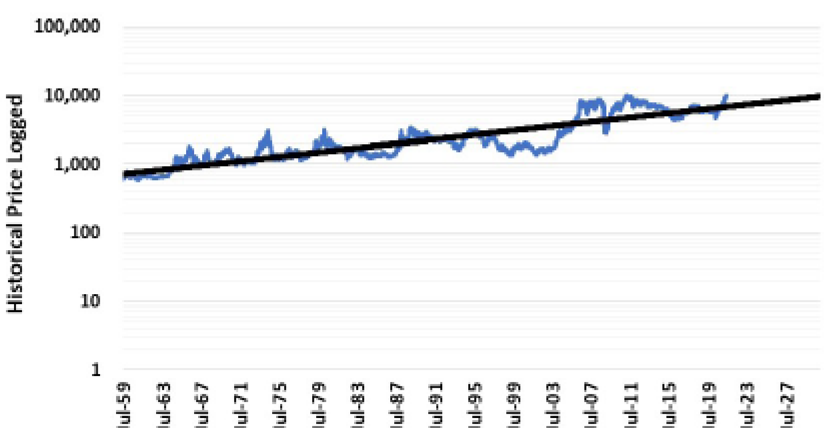


Figure 62: Long-term Logged Daily Spot Prices

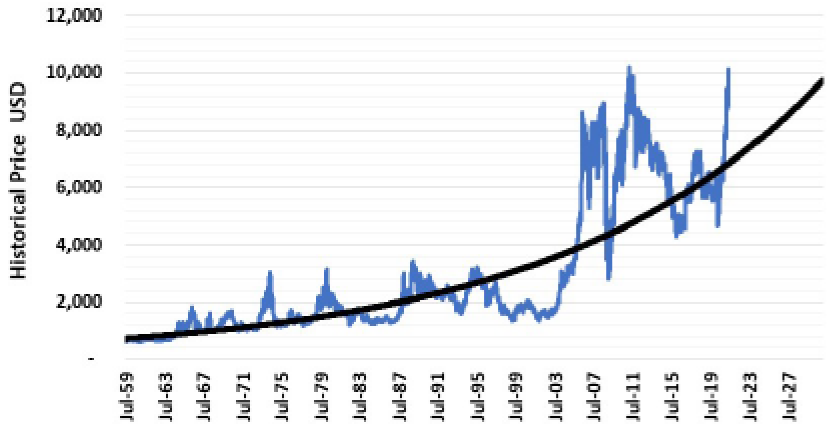


Figure 63: Antilog of Long-term Mean Copper Price

A simple methodology for applying a long-term mean price and trajectory is illustrated in Figure 62. The daily spot prices since July 1959 have been plotted on a logarithmic scale. The straight-line linear regression curve represents the long-term mean price, around which historical prices have reverted to since 1959. A straight-line linear regression is used to extrapolate the mean into the future. Once determined, the regression curve is anti-logged, as illustrated in Figure 63.

The regression curve is a function of time related data. Different time intervals will yield different results, shown in Figure 64 In pursuit of a long-term mean, to which prices will reasonably revert, a criterion for selecting and even switching between the means must be derived. By superimposing the cost profiles discussed above, the appropriate long-term mean price curve can be rationally adopted. In Figure 65, the historical excess supply moments are superimposed on the three generated mean cost curves.

The 1959 to 2021 mean sits comfortably within the cost halos from 2009 onwards. The author is of the view that this supports the adoption of the 1959 to 2021 mean price curve for understanding copper price mean reversion cost points. The 1959 to 1980 mean price curve suggests that by 2030 the copper price could reach above $/t 20 000 and should not be ignored, given the rising economic constraints working their way through the supply curve and notwithstanding the inherent inelastic nature of mine supply. The 1950 to 2000 mean price curve should not be ignored in the sense that new technology innovation could arise, in which case, the future cost curves could be driven down, as was the case during the 1980s and 1990s. The future 2030 mean price range could reasonably lie between $/t 5000 to $/t 20 000. Given 2021 macroeconomic criteria, it would be reasonable, with due regard to the cost of production, to consider that the price in 2030 will average around $/t 10 000 on the basis of these curves.

Metal price assumptions and long-term mean price should, however, not be divorced from scenario planning. “Shell has been developing possible visions of the future since the 1970s, helping generations of Shell leaders explore ways forward and make better decisions. Shell scenarios ask, “What if?” questions, encouraging leaders to consider events that may only be remote possibilities and stretch their thinking.

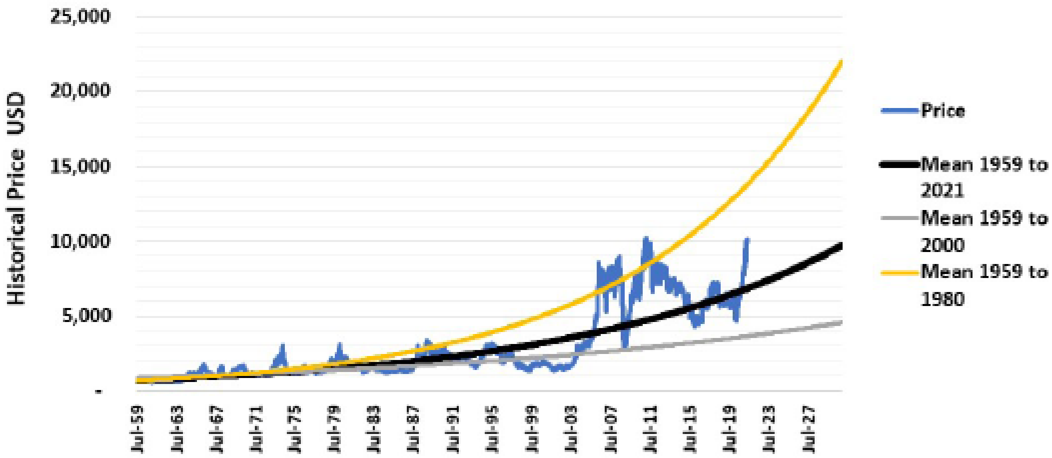


Figure 64: Alternative Long-term Means

Figure 65: Alternative Long-Term Means and Cost Curves Superimposed

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1. (Investopedia, 2019)

2. (McKinsey & Company, 2019)

3. (Learning about Commodity Cycles and Saving Investment Dynamics in a Commodity Exporting Economy, 2018)

Chapter 9

Business Economics and Sustainability

“The best way to predict the future is to create it.”

– Abraham Lincoln

Preview

Sustainability has taken on new meaning and in today’s lexicon it has been narrowed down to what is now coined ESG: Environment, Social and Governance. The threat of global warming and social justice is driving the ESG movement such that financiers are withholding funding unless miners comply with the ESG demands. In former times the ESG focus was defined as PESTEL: Political, Environmental, Social, Technological, Economics and Legal, that is clearly a more robust approach.

The risk of narrowing down the field to political, legal, social and environmental is to exclude the economics and technology. Without ore deposits, there are no mines, and without mines there is no mining ESG. The creation of mines pivots on economics and technology improvements to support society. No aspect of our modern society could have been developed without mining, and this includes motor cars, mobile phones and computers, electricity and power grids, air conditioners, stereo sets – the list goes on. These exist directly because mining provides the materials to make these toys that set modern society apart from the beasts of the jungle.

Since depleting ore deposits is typically carried out through multicycle price oscillations, mining enterprises must not only be able to design and deplete but do so in an all-weather fashion. Mining teams and mining executives need the tools and the understanding of applying economic concepts to ensure that economic sustainability is achieved in order to continually reward the providers of capital; those fearless investors who are asked to consider financing large capital intensive mining enterprises, take excessive risks and then be patient for returns over an extended timeline. If economic sustainability is absent, the supply of critical metals is imperilled and society is worse off for it.

KEY CONCEPTS

- **Operating Leverage Shutdown and Contribution Costing**
- **Regression and U-shaped Cost Curves**
- **Business Economics and Sustainability**
- **Scenarios and Risk Management**

I. Business Sustainability

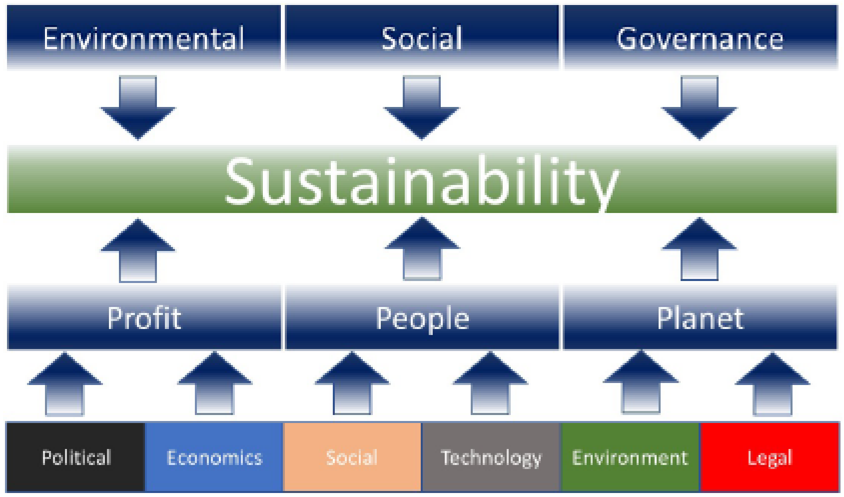

Figure: 66 Sustainability

Business sustainability in the modern lexicon refers to meeting the present generational needs without compromising future generations. The concept of sustainability is comprised of three pillars: economic, environmental and social, which is directly related to the idea of “triple bottom line”: profits, people and planet. The foundations of the modern sustainability drive are found in earlier spheres of focus, namely political, economic, social, technological, environmental and legal. Figure: 66 is an attempt to show the variously described elements of sustainability.

Ultimately, the goal of sustainability is to create a sustainable business that operates within acceptable environmental constraints, while ensuring the creation of a fairer society. All of these concepts are captured by Genius Works schematic, illustrated in Figure 67. Since this book is dedicated to mining economics, this chapter deals with specific concepts related to business economics and in doing so, does not disregard the important broader imperatives of sustainability. The Genius Works diagram succinctly highlights that sustainability does not exclude the focus on profitable growth and investor returns, by acknowledging that they form an integral part of sustainability. Mining needs investors, and therefore the focus on investor returns and profitable growth is fundamental to sustainability.

Source : Genius Work

Figure 67: Sustainable Business Practices

The concepts and ideas in this chapter are not new, but important when considering mining ventures and creating an economically sustainable business. Discussing the broader sustainability imperatives is beyond the scope of this book, save to say that mining and sustainability are not incompatible. The mining industry has made great strides over recent decades at improving its sustainability footprint. In today's business environment, subscribing to sustainability efforts and goals is not an option. Since this book is about the economics of mining, the broader subject matter of sustainability is left to other authors, better qualified to tackle this complex subject matter.

There are some basic concepts that address profitable growth and investor returns, and these are addressed below. This chapter will focus attention on operating leverage and highlights how the cost structure can assist managers to understand how to to operate when operations are no longer profitable, given the price of commodities being sold. This book has been long on describing the practice application of concepts and this chapter is no exception.

Ii. Operating Leverage

Operating leverage is a standard accounting concept which relies on the assumption that revenue and costs respond in a linear fashion. In previous chapters, the ruling hypothesis was that cost curves are non-linear. The accounting hypothesis that costs are linear has resulted in harmful business decision-making in the mining industry, and led in part to the philosophy that prioritising production would yield not only economies of scale, but higher profits due to operating leverage. The linear model does not recognise diseconomies of scale, but it is useful in describing the mechanism of operating leverage.

The Linear Model [1]

Theoretically, operating leverage owes its existence to fixed operating costs in the firm’s cost structure. The concept highlights the effects of fixed costs, to magnify the effects of changes in sales on the firm’s earnings before interest and taxes. The Degree of Operating Leverage (DOL) is the numerical measure of the firm’s operating leverage and it measures the rate at which earnings increase or decrease as sales revenue increases or decreases, for a given combination of fixed costs and variable costs. If fixed costs are higher in proportion to variable costs, a company will generate a high operating leverage ratio and the firm will generate a larger profit from each incremental sale, while the conversel holds. The concept of operating leverage is linear construct, and because of this, positive and negative changes are of equal magnitude.The higher the fixed cost to variable cost ratio, the higher the operating leverage ratio, which indicates higher profits, as sales increase because costs do not increase. This concept is better illustrated.

By way of example, mine A has a copper sales price of $/tonne 6 000, variable unit cost $/tonne 3 000 and fixed operating cost of $3 million. When copper sales increase from 2 000 tonnes to 3 000 tonnes, a 50% increase, EBITDA increases from $3.0 million to $6.0 million, a 100% increase in EBITDA. Figure 68, illustrates this idea. High fixed costs, however, can hurt cash flow when production levels are not sustained, as the delta benefits can translate into the same quantum profit erosion.

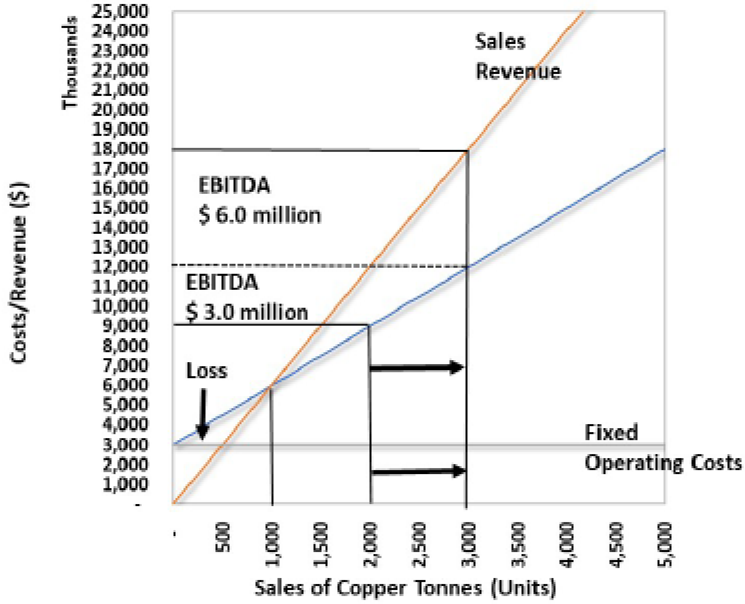

Figure 68: Ebitda For Various Levels of Sales

	Case 1 -50%		Case 2 +50%
Metal Prices	0%	0%	0%
Copper	6,000	6,000	6,000
Ore Production	-50%	0%	50%
Tonnes	100,000	100,000	100,000
Copper	1.00%	2.00%	3.00%
Metal Production			
Copper	1,000	2,000	3,000
	0%	0%	50%
Revenue	6,000,000	12,000,000	18,000,000
Costs	6,000,000	9,000,000	12,000,000
Less: Fixed Costs	3,000,000	3,000,000	3,000,000
Less: Variable Costs	3,000,000	6,000,000	9,000,000
EBITDA	0	3,000,000	6,000,000
	-100%		+100%

Table 3: Operating Leverage at Various Sales Levels by the Numbers

Table 3: Operating Leverage at various sales Levels by the Numbers shows two cases that illustrate the point:

Case 1: A 50% increase in sales from 2 000 tonnes to 3 000 tonnes, resulting in a 100% increase in EBITDA, from $3.0 million to $6.0 million.

Case 2: A 50% decrease in sales from 2 000 tonnes to 1 000 tonnes, resulting in a 100% decrease in EBITDA, from $3.0 million to $0.0 million.

The above example highlights that operating leverage works in both directions and indicates that an increase in sales has a more than proportional increase in earnings, and vice versa.

The degree of operating leverage (DOL) is a measure of an entity's operating leverage. There are various formulas to calculate this, and two are presented:

$$\text{DOL} = \frac{\text{change in EBITDA}}{\text{\% change in sales}} = 2.0$$

OR

$$DOL = \frac{\text{Total Revenue – Total Variable Costs}}{\text{Total Revenue – Total Variable Costs – Total Fixed Costs}}$$

Percentage Change Basis

Case 1:

$$DOL = \frac{100\%}{+50\%} = 2.0$$

Case 2:

$$DOL = \frac{100\%}{+50\%} = 2.0$$

Dollar basis

$$DOL \quad \frac{\$12.0 \text{ million - } \$6.0 \text{ million}}{\$12.0 \text{ million - } \$6.0 \text{ million - } \$3.0 \text{ million}} = 2.0$$

Hence base EBITDA multiplied by 2 ($3 .0 million x 2 - $6.0 million)ii

Fixed Cost and Variable Cost Substitution

Where a mine can substitute fixed costs for variable costs and increase the proportion of fixed costs, it can positively influence the DOL upward. Mining operations can substitute fixed and variable costs over a wide number of fronts, namely: contractor mining versus owner mining, owner operated plant or material toll treated, equipment purchases, use of capital lease and/or operating leases for equipment, retirement of royalty payments other than government royalties, terminating third party tolled material which only pays a unit margin for the use of the plant and hence attracting a constant margin, despite price or production scale.

Figure 69, illustrates the arithmetical benefits of substituting fixed costs with variable costs. The base production being 2 000 units of copper. By lowering the variable cost and simultaneously increasing the fixed cost, the DOL increases from 2.0 to 2.2.

Dollar basis

$$\text{DOL} \quad \frac{\$12.0\text{ million} - \$3.6\text{ million}^{i}}{\$12.0\text{ million} - \$3.6\text{ million} - \$4.8\text{ million}} = 2.2$$

A high fixed cost ratio in the cost structure clearly has benefits for earnings. Conversely, by increasing the variable cost of operations, it implies that operating leverage is sacrificed in favour of a constant margin of returns. Thus, with higher sales driven by either metal price movement and/or increased production of metals, EBITDA increases are muted with higher variable costs in the cost structure operation. Comparing the EBITDA results from Table 3 to that of Table 4 it is clear that substituting greater fixed costs is beneficial to improved EBITDA.

In a mining proposition, EBITDA can be improved by cut-off grade management, increased throughput under the battery limits of economies/diseconomies of scale, and metal price movements.

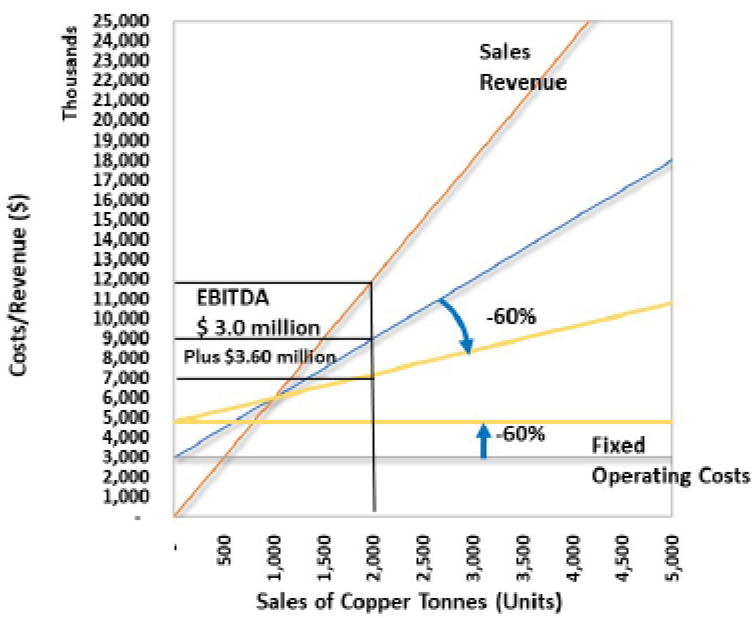

Figure 69: Variable Costs Substitution With Fixed Costs And Dol

	Case 1 -50%		Case 2 +50%
Metal Prices			
Copper	6,000	6,000	6,000
Ore Production	**-50%**	**0%**	**50%**
Tonnes	100,000	100,000	100,000
Copper	1.00%	2.00%	3.00%
Metal Production			
Copper	1,000	2,000	3,000
	0%	**0%**	**0%**
Revenue	6,000,000	12,000,000	18,000,000
		25%	53%
Costs	**6,000,000**	**9,000,000**	**8,400,000**
Less: Fixed Costs	3,000,000	3,000,000	4,800,000
Less: Variable Costs	3,000,000	6,000,000	3,600,000
EBITDA	**0**	**3,000,000**	**9,600,000**
	-100%		+220%

Table 4: Ebitda Changes With Fixed Cost Substitution

The Non-Slinear Model

As described in previous chapters, the total cost curve is a non-linear function because of diminishing returns. Applying DOL to non-linear curves is mathematically more complicated but can be rapidly solved with assistance of a computer algorithm. The linear model is useful for explaining the theoretical idea of DOL, but it ignores the idea of diminishing returns. The impact of this is described in Figure 70. The microeconomic curve that recognises diseconomies of scale or diminishing returns is represented by an S-curve, while the simplistic variable cost is a sloped line. Point A indicates the revenue moment for 2 000 tonnes of copper production. Points B and C indicate the respective cost moments, based on a straight line, versus the S-shaped curve. The straight line suggests less EBITDA at 2 000 tonnes production than the S-curve, being \$3.0 million versus \$5.5 million, given an S-shaped cost curve. Expanding production to 3.0 million tonnes of production on the straight-line, assumption suggests an EBITDA of $6.0 million (points D and F), whereas the S-curve suggests EBITDA of $3.0 million (points D and E).

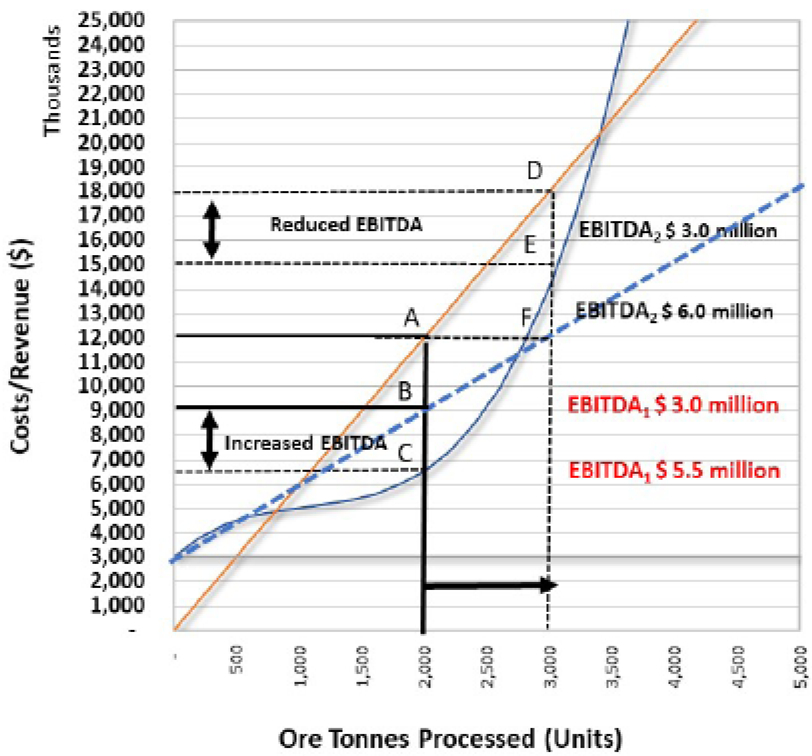

Figure 70: Operating Leverage Under Diminishing Returns TTo Scale

At face value, it would appear that DOL limited application is in fact the benefits of increased production yields, lower EBITDA. This analysis does indicate that an optimisation is required, and which points to the battery limits discussed in previous chapters. Maximising year-on-year profits means that production should increase to the point where marginal revenue and marginal costs intersect, versus maximising life of Life of Mine profits, which is defined by the intersection of marginal costs and average costs. The optimal choice and the DOL that can be gained between these battery limits is a critical benefit to managing EBITDA in a cyclical metal price environment.

Iii. Optimal Fixed Cost and Variable Cost Combination

The question is often posed as to the optimal fixed cost and variable cost combination. The short answer is that there is none. The combination of fixed cost versus variable costs is a function of the economic environment that a mine is located in. The analysis of the fixed and variable costs, however, allows miners to understand the trade-offs between higher DOL versus lower DOL, driven by strategic considerations. For example, in an environment where the labour force is highly unionised and experiences low productivity, a high fixed cost ratio would add risk to cash flows. In this instance and to control the effects of unionisation, one strategy to consider would be to make as many costs variable as possible. Another is to have better relations with stakeholders, to benefit from better operating leverage.

The approach described in this book is to run all combinations of fixed and variable costs along the production function, with the cost being connected to the grade tonnage curve, to ascertain the maximising moments of the grade and minimum costs moments. Understanding the various maximising moments and the relative positions of these moments, assists the management team in understanding the feasibility of achieving a desired position along the industry cost curve. Miners seek to be within the first quartile as a goal, and the reality is that this may not be a feasible option. It is better to understand the feasible option and the cash generative feasible position, than to suffer the misbelief that this desired positioning is achievable.

The scale of the operation will also influence the optimal variable and fixed cost mix. The scale of operation is, in turn, influenced by the ore deposit’s economic signature and by the optimal capital intensity required to maximise returns. Simply increasing scale without considering the capacity of the ore deposit runs the risk of over-capitalisation and depressing return on investment. As this book has shown, the optimal cost structure is determined by simulating returns through the production scale alternatives by dynamically adjusting the input variables, to discover the maximum yield that a particular ore deposit can yield.

IV. Shutdown and Contribution Costing

“The possibility that a firm may earn losses raises a question: Can the firm not avoid losses by shutting down and not producing at all? The answer is that shutting down can reduce variable costs to zero, but in the short run, the firm has already committed to pay its fixed costs. As a result, if the firm produces a quantity of zero, it will still make losses because it would still need to pay for its fixed costs. Ergo, when a firm is experiencing losses, it must face the question: Should it continue producing or should it shut down?” This dilemma is what miners had to wrestle with, during the 2015 copper price downturn. In a falling price environment such as in 2015 when metals prices, and in particular the copper price, which fell from above $/tonne 6 000 to a low of $/tonne 4 200, miners wanted to know at what point would they need to shut down their operations. The answers are better explained through illustration.

In Figure 71 P1 (Price) is above the Total Average Costs and profits are realised. At P2, the metal’s price and costs are equal or at breakeven and no profits are realised, no losses are incurred, and therefore the operation must continue to operate.

At P3, the metal price is below the ATC, but continuing operations in the short run means that the loss incurred is only a fraction of the variable cost of operating. The operation still covers some variable cost and fully covers the fixed cost of operations. In this scenario, the operation should continue operating, as the cost of closure will be larger than carrying the proportion loss.

In Figure 72, P5 is below the Average Variable Cost curve and the mines contribution to Fixed Costs is negative. The metal price at which the mine should be shut down, is indicated at P4. Constructing these curves to guide the timing of the decision process, is easily accomplished by using econometric techniques, as described below:

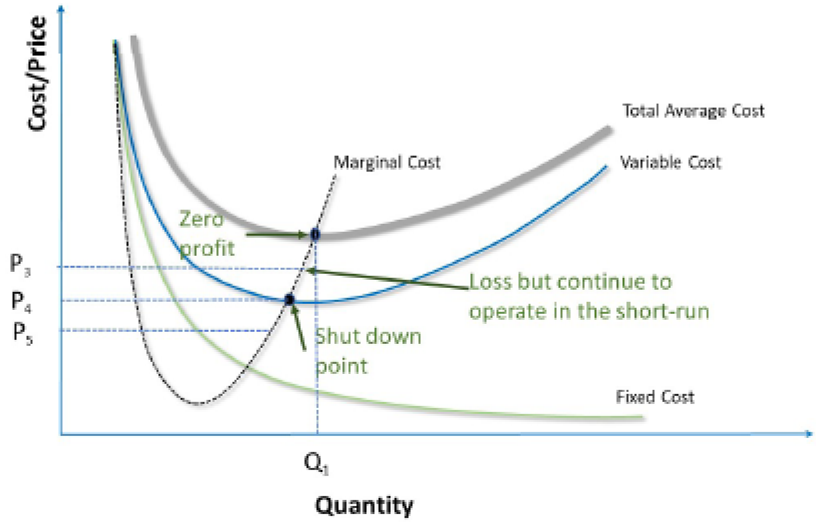

Figure 71: Economic Rationale to Continue Operations

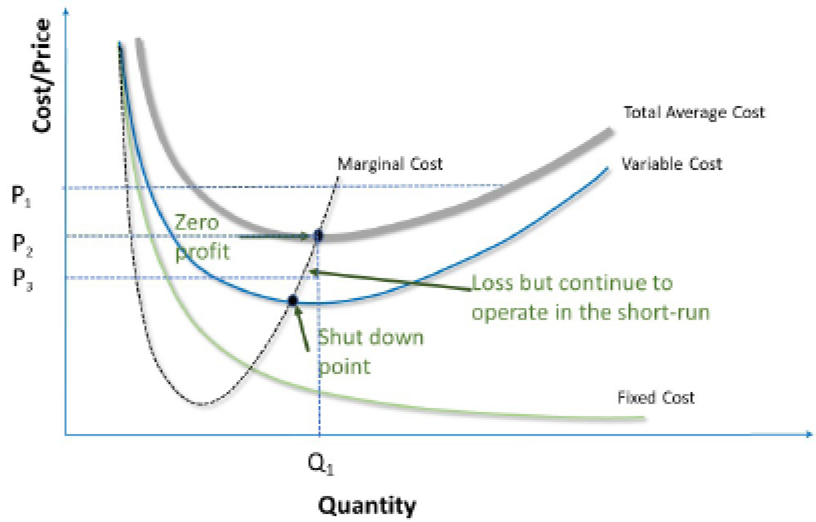

Figure 72: Economic Rationale to Shutdown Operation

V. Regression and third order S-shaped Cost Curves Derived

The definition of econometrics is the quantitative measurement and analysis of actual economic and business phenomena, which attempts to quantify economic reality by bridging the gap between economic theory and business reality. The graphs set out in the previous section can be described using econometric techniques. This section will provide a general approach to constructing the cost curves, given production information, and finer points are well covered by Studemund (1992). This section seeks to outline the basic technique that relies upon Studemund's work: Using Econometrics, a Practical Guide.

Single Equation Linear Regression Analysis (SLRA) is a tool used in econometrics to quantify data and correlate it to an economic hypothesis. Studemund outlines the following key steps when applying SLRA to data:

- Theoretical considerations usually dictate the form of a regression model;

- The basic technique involved in deciding on a functional form is to choose a shape that best exemplifies the underlying economic or business principles and then to use the mathematical form that produces that shape; and

- The choice of a functional form is a vital step in applied regression, requiring a good understanding of economic theory and common sense.[2]

The next steps outlined by Studemund when applying SLRA are:

- Data collection (sufficiently descriptive, sufficiently granular);

- Estimation and evaluation of the equation (Excel regression tool); and

- Results (interpretation based on common sense).

The application of SLRA is a little more complex when the data contains serial correlation, auto correlation and heteroskedastic trends. However, these basic steps provide the basic steps to constructing an operations cost curve.

Model Specification

This book has highlighted the application for the second and third-degree polynomial cost curves, based on theoretical microeconomic principles. The choice of a functional form is either the S-shaped curve or the U-shaped cost curve. The general formulas for the S-shaped cost curve and the U-shaped cost curve are described below.

Model Specification

This book has highlighted the application for the second and third-degree polynomial cost curves, based on theoretical microeconomic principles. The choice of a functional form is either the S-shaped curve or the U-shaped cost curve. The general formulas for the S-shaped cost curve and the U-shaped cost curve are described below.

- absolute cost functional form = ax3-bx2+cx+fixed costs [3]

- Unit cost functional form = ax^2-bx+Unit Fixed Costs

Ergo, starting point in econometrics is to specify the functional form that best exemplifies the underlying economic principles. In this case, the economic principles are the recognition of diminishing returns, and this is embedded in the functional forms, described above.

Data collection - Step (1)

Typically, the data required to run the microeconomic analysis entails sourcing production data and related cost data. Figure 73, shows three years of cost data. Production data includes mined tonnes, tonnes sent to the processing plant, stockpiled tonnes and processed tonnes. Cost data should include: direct activity costs (mining, processing, general and administration costs), C(1), AISC and Total Costs. This data breakdown provides sufficient granularity to enable the analysts to consider the cost elasticity of various levels of costs, to better assess cost responses to production output along the value chain.

Empirical data used to demonstrate the application of SLRA analysis has been sourced from several and reputable mining companies and combined and hybridised for explanatory purposes. It is worthwhile to understand the accounting treatment of the data received, namely is it based on cash cost accounting principles, or financial accounting principles? Understanding what accounting methodology has been applied is helpful in deciphering the nature of data point scatter, and the interpretation of the regression analysis. Cost accounting is favoured, as it is an attempt to match sales to costs and hence moderates the data spikes that can affect the regression averaging.

Data normalisation – Step (2)

Prior to applying a regression equation, the data must be normalised for inflation. Historical data is inflated to current terms, i.e., historical data is considered nominal and inflated to current real terms. In general regression issues of serial correlation, auto correlation and heteroskedasticity are ignored in this basic application but should be considered in the ordinary course applying SLRA. The subject matter, however, is for a more advanced discussion, which is beyond the scope of this book. The reader is referred to Studemund (1992), for further insight on these issues.

Estimation and evaluation of the equation – Step (3)

Excel provides a convenient software tool to run the regression mathematics of a data set. As highlighted earlier, linear regression does not refer to straight line regression only. Linear regression is defined as linearity in the coefficients, rather than in the variables, and hence a large number of non-linear slopes can be used to describe the underlying theoretical model.

The data collected in step (3), is quantum costs and therefore the hypothesised curve to fit the data set, is the S-curve or the polynomial equation:

$$y = ax^3 - bx^2 + cx + d$$

Where:

y = cost estimate

Results – Step (4)

The Excel regression formally allows for the calculation of the coefficients that define the regression curve. An Excel model is constructed to calculate the quantum costs at varying regular production intervals, to replicate the Total Cost Curve and cost structure. The derivative of these curves, as has been previously described, are the U-shaped cost curves.

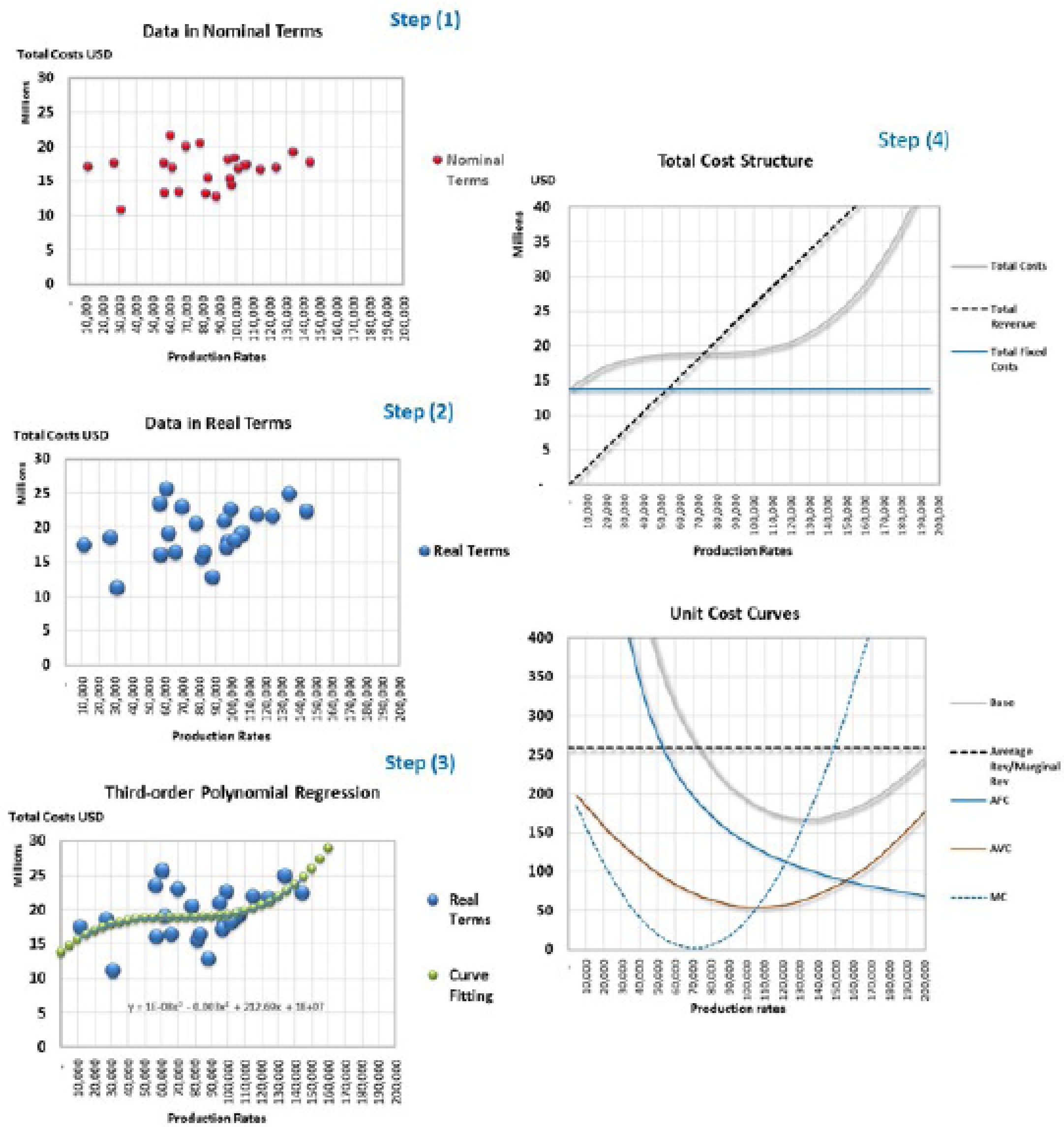

Figure 73: Steps in Applying Single Equation Linear Regression Analysis

The regression results yield the coefficients for the regression curve, yielding the average cost estimate, at varying levels of production. This curve can then be applied to a constantly increasing production profile, to describe and define the empirical S-shaped cost curve and its derivative, being the U-shaped cost curve, and used pervasively in microeconomics to show the microeconomic responses to production and cost changes.

Deriving these curves allows for the determination of a mine's cost structure, i.e. its fixed and variables costs curves. This then allows analysis of understanding how to approach issues such as right-sizing and optimising a mining business from an economic perspective.

VI. Business Sustainability

The distinction is made between business sustainability and what is now commonly referred to as ESG: Environment, Social and Governance issues that can affect business sustainability. Business sustainability has been previously and correctly been more broadly defined by Porter, as Political, Economic, Social, Environmental and Legal (PESTEL) factors that may affect an organisation or mine. Since this book focuses on a mine's and/or a mining company's economics, we will limit the discussion on sustainability to the economics of operating the business, i.e. business economics and economic factors of sustainability.

Two critical aspects that can fundamentally address business economics sustainability are the idea that the mine pit or underground production has to match the plant processing rate. In an environment where grades are falling and geometallurgy characteristics are becoming ever more complex, the ability to control the grade and ore type presented to the processing plant has become a critical competitive advantage.

Processing plants are designed on a particular feed or head grade. If grades are lower than the designed grade, a lower recovery factor of the contained metals will be realised. Notwithstanding this, broadly speaking the grades presented to the processing plant will determine the volumes of ore to be treated. The lower the grade and higher the volume, the larger the processing footprint. The higher the volumes to be treated, the higher the variable.

VII. Beating the NPV

The four basic steps outlined, illustrate how operational data can be used to derive the cost curves for a producing mine. The construction of these curves is useful in understanding where the current levels of production cluster and therefore the determination as to whether the operation is achieving the minimum unit cost of production. The battery limits of production can also be calculated and illustrated, providing management teams with the means to understand the microeconomic responses that are available to maximise Life of Mine, and annual returns notwithstanding, applying the cost structure to the ore deposit signature being mined.

VIII. Mining Cost Metrics

Historically, miners have considered that an increase in ore processed will lower their unit costs of production. While this book has shown that costs rise at a point along the production curve, it has not explicitly drawn attention to the impact of grade. Miners have two cost measures, namely: cost per tonne of ore produced and cost of metal produced. The cost of ore is directly related to the operational activities, i.e. drilling, blasting, hauling, crushing, grinding, extracting, transporting, etc. and the scale of designed operations. The cost of metals is impacted by the variance of estimated realised grades, dilution and metal losses, resulting in head grades and metal recoveries being the result of complex comminution, and chemistry.

Hence the unit cost of ore production can remain constant or even fall with increased ore production, while simultaneous metal unit costs rise. If the increased level of production causes grades to fall, lower cut-off grades are applied and therefore face grades, or increased volumes, which adds more dilution affecting head grades or increased ore production, affecting recoveries. The unit cost of ore processed might fall by reduced metal received, which means that the unit cost of metal production increases. To analyse the sensitivity of the two measures on cost performance, the cost structure must be combined with the grade tonnage curves to indicate the impacts on grade, and the volumes of metals which will be extracted as a result of increasing ore throughput and the concomitant change on cut-off grades. Of course, the choice of mining methodology affects the head grades and again, this can be modelled to determine the impact of alternative mining methodologies and the impact on costs, namely the unit cost of ore produced, and the unit cost of metal produced.

IX. Scenarios and Risk Management

Economic sustainability requires strategic planners to anticipate future trends in metals prices. Pre-2000 miners did not anticipate the commodity boom, and many were hesitant to acknowledge the commodity upswing until late into the super-cycle. This meant that by the time they had committed billions of dollars to their project pipelines, inelastic supply (supply that is not easily tapered when demand falls) meant that the market would be over-supplied when prices fell. At the end of 2013, prices weakened, and the belief that the market would be over-supplied as growth from China softened, led prices to spiral toward the cash cost of production.

Fast forward to 2021 and a new super-cycle is materialising. This time, miners are wary and reluctant to trigger the button to increase production. As prices rise, governments are seeking rents, and numerous governments are raising taxes, while other countries are changing to socialist governments, to cash in on record high metal prices. Case in point, in 2021 the world's two largest copper producers are in Chile and Peru. Chile is considering hiking taxes, while Peru voted in a socialist government, bent on nationalising mining assets. It would seem that miners are stuck between a rock and a hard place – volume over value is impaired and value of volume is taxed. Miners need to find the equilibrium.

In the previous chapter, the idea of scenario planning was introduced. Shell has been developing scenarios within the company for almost 50 years. These scenarios are intended to stretch the thinking of executives, and then serve to help in making crucial choices in times of uncertainty or during periods of transition. Shell claims that the sheer breadth and depth of perspectives gained from these scenarios has assisted the company in creating successful partnerships and initiatives around the world, on individual country levels, as well as regional and global.[4]

These scenarios are described as fundamentally plausible and challenging descriptions of the future landscape. "Shell-style scenario planning has never really been about predicting the future. Its value lies in how scenarios are embedded in, and provide vital links between organisational processes, such as strategy making, innovation, risk management, public affairs and leadership development. It has helped break the habit ingrained in most corporate planning, of assuming that the future will look much like the present. As unthreatening stories, scenarios enable Shell executives to open their minds to previously inconceivable or imperceptible developments."[5]

Harvard Business Review (HBR) has summarised the key benefits of what they have coined “strategic foresight”, namely: (1) enhancing the capacity to perceive change, (2) enhancing capacity to interpret and respond to change, (3) influencing other actors and (4) enhancing the capacity for organisational learning.

The principles of Shells scenario planning have been outlined by HBR as follows:

● Make scenarios plausible, not probable

Scenarios are not predictions, since the ability to identify all the forces at play is not possible. The essence of scenario planning is to challenge the official view and to create a self-awareness in approaching the future.

● Strike a balance between relevant and challenging

Shell’s scenarios are designed to be more than disruptive and challenging; they have to be relevant to executives. To be successful, scenarios need to consider unexpected developments and encourage strategic conversations, which go beyond the incremental, comfortable and familiar progression, customary in a consensus culture. To remain relevant, the scenarios have to have the necessary intellectual agility and operational flexibility, by shifting beyond global, to more ‘sliced and diced’ scenarios.

● Tell stories that are memorable, yet disposable

The greatest power of scenarios, as distinct from forecasts, is that they tell stories. The challenge with forecasts is that they simply extrapolate the present into the future. Scenarios consciously break this habit. They introduce discontinuities, so that conversations about strategy, which lie at the heart of any organisation’s capacity to adapt, can encompass something different from the present.

● Add numbers to narrative

Scenarios are meant to harness intuition, and Shell’s scenarios have never been developed from mechanistic modelling. Despite this, they have always been associated with quantification, enhancing internal consistency, revealing deep story logic and systemic insight, and illustrating outcomes, using the language of numbers that characterises most corporate cultures.

● Manage disagreement as an asset

Scenarios have the power to engage and open the minds of decision-makers so that they pay attention to novel, less comfortable and weaker signals of change and prepare for discontinuity and surprise. Scenarios also provide a way to manage disagreement about company strategy or priorities, and help disturb the business-as-usual view which tends to result from wishful thinking, or the linear extrapolation of current trends.

● Fit into a broader strategic management system

Scenarios provide the right framework for appreciating fundamental long-term choice, which is not the same as next year's annual plan. The challenge in effective scenario work is to go beyond the usual strategic focus on current trends and competitive positioning (profitability, for example), to find the right scale of observation. The next challenge is to look for some degree of fit between the company's core capabilities and the variety of plausible future conditions. Three essential starting points for corporate strategy: global scenarios, competitive positioning and strategic vision. The first represents the world of possibility, the second the world of relativity, and the third the world of creativity. The success of the strategic vision thus depends on matching capabilities and context. Scenarios can help that vision evolve and become a source of dynamism.

Scenario planning helps organisations perceive risks and opportunities more broadly, to imagine potential futures and different scenarios that might challenge their assumptions, and to spot sources of risk that may otherwise go undetected. Scenario planning and war-gaming bring the future into the present in vivid ways which illuminate not only the risk landscape, but also the potential impacts of specific risks and responses. War-gaming, for its part, enables organisations to create, test, rehearse and refine strategies and enhance decision-making amid uncertainty. Both are essential tools for managing risk, and alongside risk governance, risk sensing and portfolio optimisation, they are key enablers of the risk-intelligent enterprise. The goal of a risk management programme, of course, is to prepare the organisation for future risks and upside opportunities, and reaching that end state can be elusive. Common impediments include untested assumptions about the impact of potential future conditions and events, a discomfort with uncertainty, and the failure to identify the full range of organisational responses and their potential effects. Scenario planning and war-gaming are complementary, as they enhance decision-making by relating specific uncertainties to the strategies, decisions and initiatives under consideration. The goal is to visualise various futures, any of which may, or may not come to pass, but equip management to better prepare the organisation for whatever the future might bring, by considering various futures in a creative, yet rigorous way that management can not only feel more confidently, but may emerge better prepared for the uncertainties and risks that lie ahead. Scenario planning and war-gaming are designed to enhance risk management by combining creativity and rigour to chart pathways that would otherwise be undiscoverable. This approach contributes a strong outside-in point of view, which corrects for the natural tendency of some organisations to view themselves and their world essentially through their own lens.[6]

X. Project Value Tracking

In his seminal work, Gordon Smith, the former executive Head of Strategy for Anglo Platinum, stated that for a mining company to create sustainable value from mineral assets, it is necessary to:

• Optimize the mineral asset portfolio to align with strategic and business objectives;

• Create and operate long-term assets within an anticipated long-term business environment; and

• Create and retain flexibility in the short-term tactical response, allowing effective response to long-term shifts in the business environment.

To accomplish this, it is necessary to:

• Allow the fixed physical nature of the mineral asset(s) to drive definition of the optimal (lowest capital cost, lowest operating cost, highest efficiency, maximized cash flow) technical solution to mining and concentrating activities;

• Define and apply different business environment perspectives, world views or scenarios to determine possible economic viability under the different perspectives, i.e. define the value proposition under different scenarios – what are the options?

• Develop and resource a portfolio of production entities from the mineral asset portfolio that creates flexibility to near- and longer-term business environment shifts, i.e. a production mix that allows variation of output (metals, operating cost, capital intensity) to respond to market demand and pricing[7].

To achieve these goals this book has described various tools and techniques that can be applied in a systematic way to ensure that the ore deposit's value proposition is captured. Value creation and sustainable value management have to be tracked and adjustment has to be made to ensure that value expected is value achieved in a dynamic external and internal environment.

The implementation of a given strategic long-term plan is subject to adjustment according to short-term changes in market demand and general economic circumstances. The ability to effectively adjust to changing circumstances is a function of the nature / diversity of the mineral asset portfolio, in particular the number, variety and output capacity of existing production sites and potential projects available and information for decision making.[8]

Under Smith's guidance, Anglo American Platinum developed a Project Value Tracking (PVT) tool in the 2000s. The tool takes the form of a waterfall chart, which illustrates the relative importance of various external (environmental variables) and internal (management levers) factors that have caused the NPV to change since the original view baseline model.[9]

A typical waterfall graph is illustrated Figure 74 and is the basis for the systematic and periodic tracking of the business case value of an operation or a project that allows for continuous portfolio optimization and managerial capital allocation to maximize mineral asset portfolio returns.

The intention of the PVT is to determine the variables that affect the original expected value and rate of return at the initiation of the project. This tool provides a strategic overview of how the dynamic variables are affecting value creation through time and changing price cycles. Too often the original investment criteria are lost after the first blast of ore and management focus on short-term outcomes that damage the investment rationale.

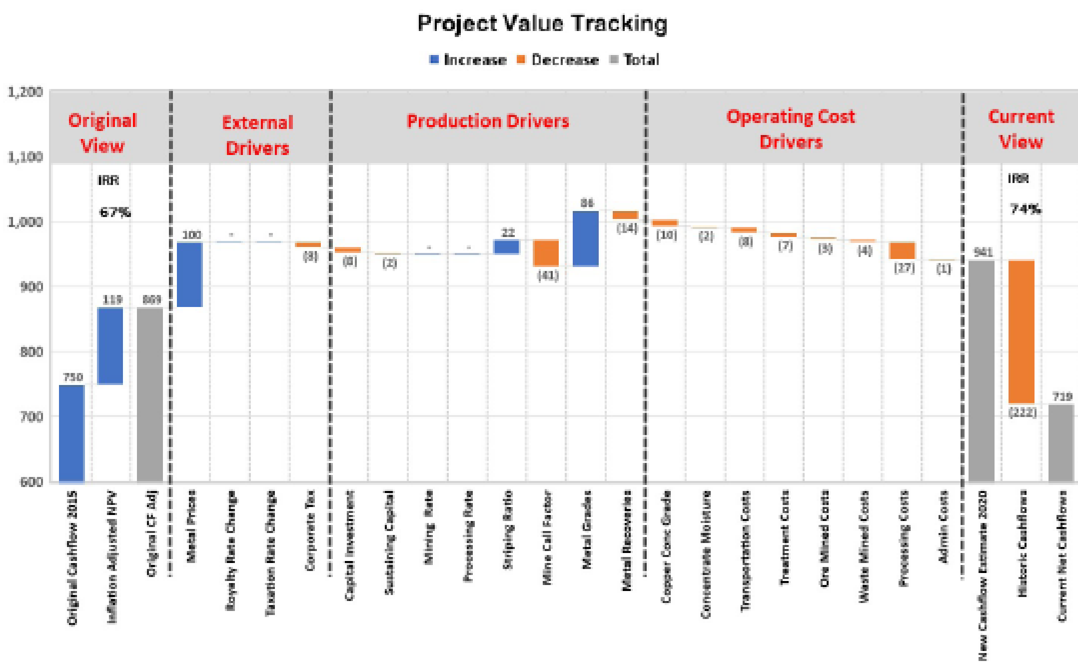

Figure 74: Project Value Tracking Tool

The PVT tool is useful for highlighting the variables that affect the expected return through time and also highlights which variables have materially impacted. Too often management gets distracted and exerts vast amounts of time, energy and resources to tincker with performance that makes little incremental benefits to the overall investment thesis. Once the project has been initiated, management teams have a tool to stress test their decision and gauge the impact of what they intend doing on the investment outcomes and investor expectations.

Briefly, the PVT can either be expressed as NPV0% or at a discounted rate. The graphs can be easily adjusted if automated. In the above illustration no discount has been applied so that the present value cash flows can be considered and the variables that contribute to value improvement or value shrinkage can be highlighted.

Combining the NPV with the project IRRs is significant as the residual money stream continues earning at a rate of return despite the NPV decay over time. For investment purposes management teams looking to replace or add to their mining asset portfolio must consider an Investment Opportunity Schedule (Appendix 1) against the firm’s Weight Marginal Cost of capital and accept only those projects that beat the cost of capital. Knowing what a project’s cash streams are earning is critical to ensure sustainable long-term returns to the investment portfolio. The PVT also ensures that the investment activity is communicated to management teams and the tactical actions are aligned with long-term investment criteria and expectations.

In investment theory, money is invested to secure a cash flow stream for a given rate of return. In mining projects this rate of return is typically expressed as the Internal Rate of Return (IRR). The Project Value Tracking also provides the ability to track year on year the IRR yield. This is shown in Figure 75 and useful when considering the mining asset portfolio and which projects should be adopted to replace exhausting assets.Grade optimization will provide the deciding factor for ensuring that new projects are optimized to yield maximum returns in the face of global ore deposits that have lower and declining grades. The Project’s IRR Value Path is also important when considering exiting projects. Because the NPV residual value decays, the rate of return on residual cash streams must be replaced. Residual cash streams generally have less risk than new cash streams and considering this is a critical strategic discussion.

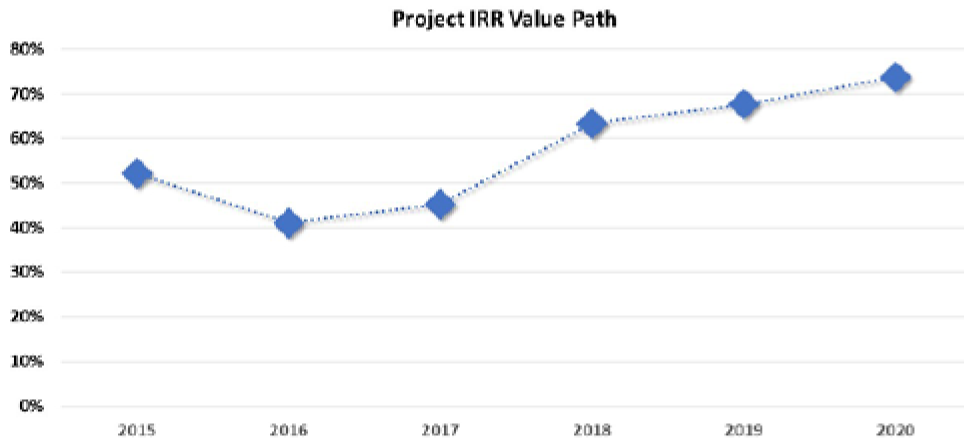

Figure 75: Irr Price Path Trajectory

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3. (Studemund, 1992)
4. (Shell, 2021)
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6. (The Wall Street Journal, 2021)

Chapter 10

Case Study

"It always seems impossible until it is done."

– Nelson Mandela

This case study is based on a real-world mining economics exercise. The essence of this case study is to demonstrate that the concepts that have been discussed in this book are readily usable and a demonstration to Minnitt's frustration a decade ago that economic concepts must be realized in practically usable ways. This case study is intended to demonstrate the applied use of microeconomic concepts described that are now readily useful in the real world of mining. This is an important development as it directly considers the ore deposit's economic capacity and by applying a comprehensive analysis of the optimal cost structure to better determine the optimal economic level of scale of operations to maximise profitability. The approach applied is to use different projects to avoid disclosing information with respect to a particular project or its outcomes.

This book has sought to demonstrate a deeper appreciation for the application of economics in mine design and mining operations. However, there will always be finer points to consider and worthy of doctoral theses. The case study below focuses on the economic analysis that should be undertaken before feasibility studies are initiated to provide mine planners with the key design parameters that have to date been missing. This modelling is also readily usable to enhance operational performance by determining the optimal economic moments of installed capacity and comparing current performance. The key points of demonstration in this chapter are limited to the following as it requires more complexity. Simple regression analysis is used to determine current operational moments:

- Ore deposit analysis

- By-product analysis

- Cut-off grade optimization and cost structure simulations

- Hill of Value outcome

- Monte Carlo analysis

● Ore Deposit Analysis

The importance of understanding an ore deposit's economics signature cannot be over-emphasized. Miners who claim that the ore body dictates their business model without a deep knowledge of the ore deposit's economic signature will have little insight into how to maximise and sustain the economic performance of their mining operations. As is often the case they will continue to focus their efforts on the engineering of mining rather than the economics of mining. Focused on the engineering of mining led miners astray during the last super-cycle, given the fervent belief that prioritizing volumes would drive greater efficiencies – it did not.

Since ore deposits are not supermarkets where the shopper can go to neatly stacked aisles and select the goods they wish to buy, ore deposits represent a supermarket that requires the consumer to buy all the products that surround the desired product. To be efficient in the many products that surround the products of interest which must be mined to minimize costs, statistics lends a hand. Since ore deposit supermarkets are not randomly stocked and follow a very clearly defined geochemical path, the geochemical signatures can be described by a grade tonnage curve and this is the first step in the microeconomic analysis of an ore deposit. What does the shop floor look like?

● Determining the Grade Tonnage Curves and the Metal Distributions for each of the deposits

The point that ore deposits are all unique, having unique geochemical signatures and therefore unique economic signatures, is clearly seen when comparing deposits' grade tonnage curves.

Figure 76 illustrates the market differences in the potential ore distributions as defined by applying cut-off grades. The mining methodology of deposit 2 versus deposits 1 and 3 will be quite different. Given the steepness of the curve of deposit 2 and the lack of variability, a high-volume mining methodology would likely favour its optimal economic extraction while the other two deposits would better support more selective mining methodologies to maximise economic efficiencies.

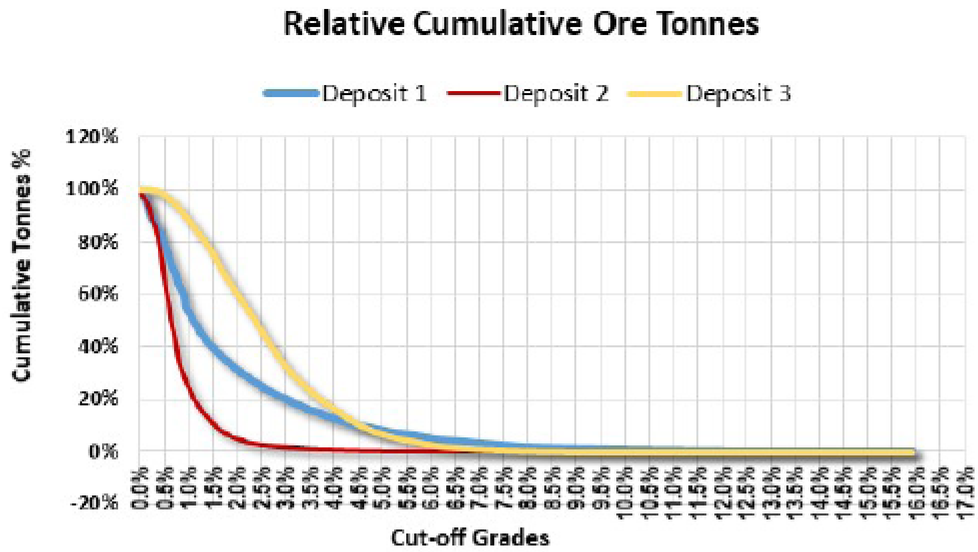


Figure 76: Relative Grade Tonnage Ore Curve Comparison

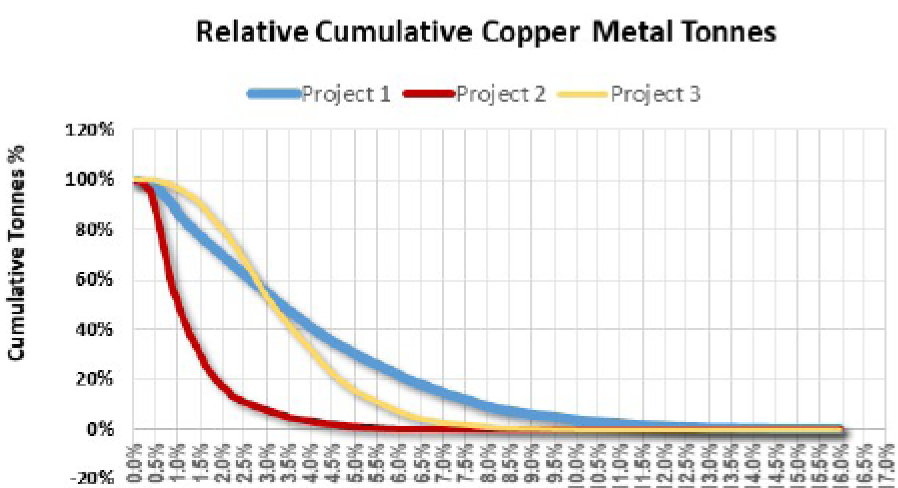


Figure 77: Relative Grade Tonnage Metals Curve Comparison

Figure 77 similarly shows the grade tonnage curve comparison of the contained metals for each of the deposits and the metal signature. The metals signatures are also observed to be different to the ore signatures which will have a direct influence on the economics and free cash flows that can be harvested from each of the deposits.

● By-product Analysis and Signatures

Figure 78 illustrates the correlation between copper and cobalt in the three deposits. Many deposits have by-products, and many have multiple by-products. Optimising an ore deposit to maximise profitability requires that all contained metals must be considered in an economic analysis. The default position when optimising a deposit is to consider the by-product grade as static in the model construct. Applying this assumption necessarily reduces the quality of the optimization study when considering the extent of the by-product variability between deposits and also between metals.

Figure 79 illustrates the comparison between the copper cut-off and the cobalt grades. The noise in the figure above reduces and the dynamic nature of the cobalt grade can be referenced to the copper cut-off when modelling he economics of each of the deposits.

● Cut-off Grade Optimization and Cost Structure Simulations

Since the optimal cost structure is unknown in both, a function of the ore deposit signature and the extraction methods are to be applied. The starting point in this analysis is not to consider the feasibility of mining and processing methods but simply to determine the viability of the ore deposit by discovering the optimal moments. Once the most viable solution is found, the feasibility of that solution can then be considered. It is likely that the feasible solution will not match the most viable solution; however, the design teams will be challenged to achieve the most viable outcome. Elon Musk was informed that landing rocket boosters was impossible and that NASA was at it for decades with state funding. Musk knew the benefits of achieving the impossible. Today Musk lands booster back on earth. The analogy is useful because design teams default to simply applying known solutions in a “one shoe fits all” approach. By understanding the maximum economic capacities of ore deposits, design teams are forced to apply disruptive thinking to achieve the optimally viable solution.

The determination of the optimal moments for cut-off grades shown in Figure 80 is a function of the cost structure applied and the ore deposit's economic signature, combining the ore deposit's signature and running multiple cost structure alternatives solutions shown in Figure 81. As described in the book, the optimal solutions consider the capital intensity, the construction period and alternative cost structures in a dynamic fashion to derive multiple optimal solutions. The solution to be selected is determined by constructing a Hill of Value.

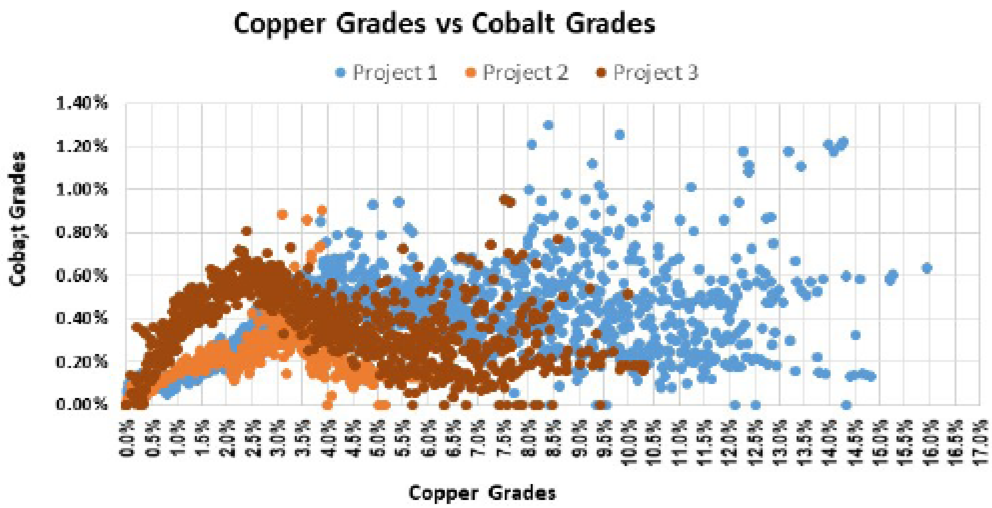


Figure 78: Copper Grades Versus Cobalt Grades

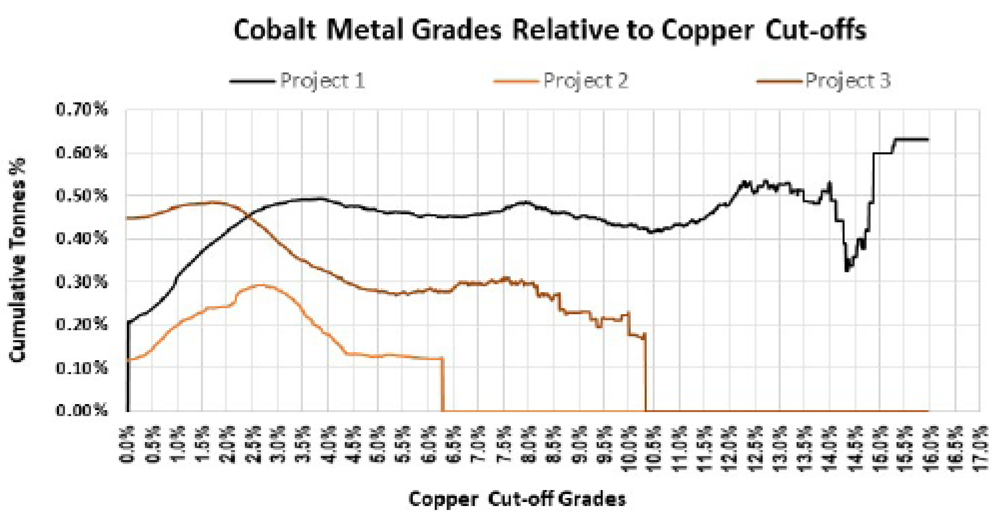


Figure 79: Cobalt Grades Versus Copper Cut-off Grade

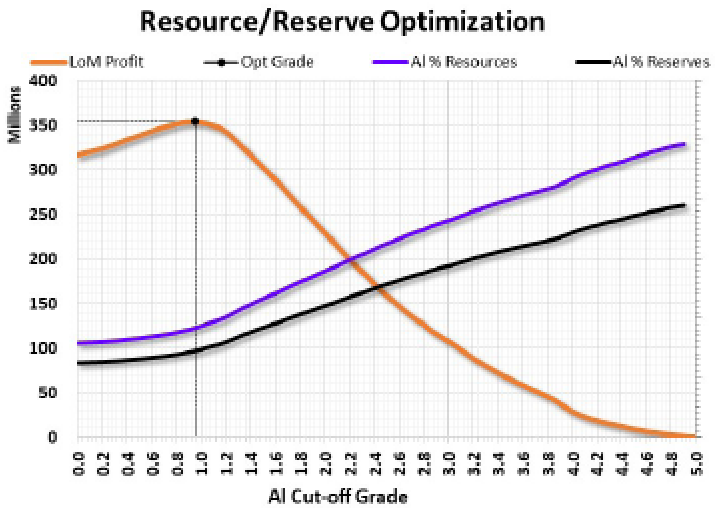


Figure 80: Cut-Off Grade Optimization Determination

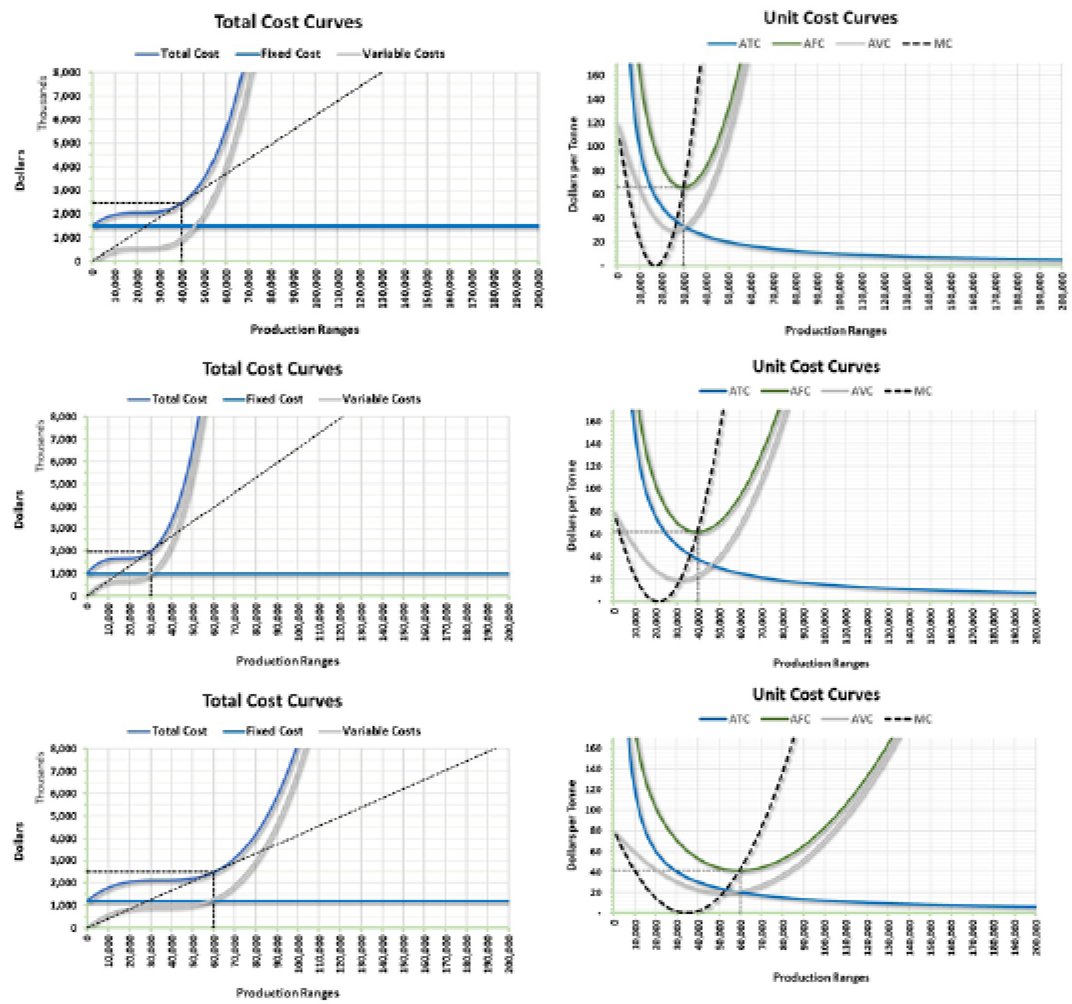


Figure 81: Multiple Simulated Cost Structure Optimal Solutions

● Hill of Value outcome

The construction of the Hill of Value is the final filter with respect to the optimisation procedure. As described in this book, the Hill of Value compares the cut-off grades against the production scale alternatives and plots he NPV as the ultimate optimization metric.

In this exercise the Hill of Value is represented in Figure 82 This exercise illustrates the optimal economic scale that maximises the economics of the contained ore deposit in one of the pits described above.

The optimal cost structure related to the peak value is shown Figure 83 at the intersection of the marginal cost and Average Total Cost curves. The corresponding optimal moments; the cut-off at 1.25% Cu and a production rate of 60 000 tonnes processed per month is shown in Figure 84.

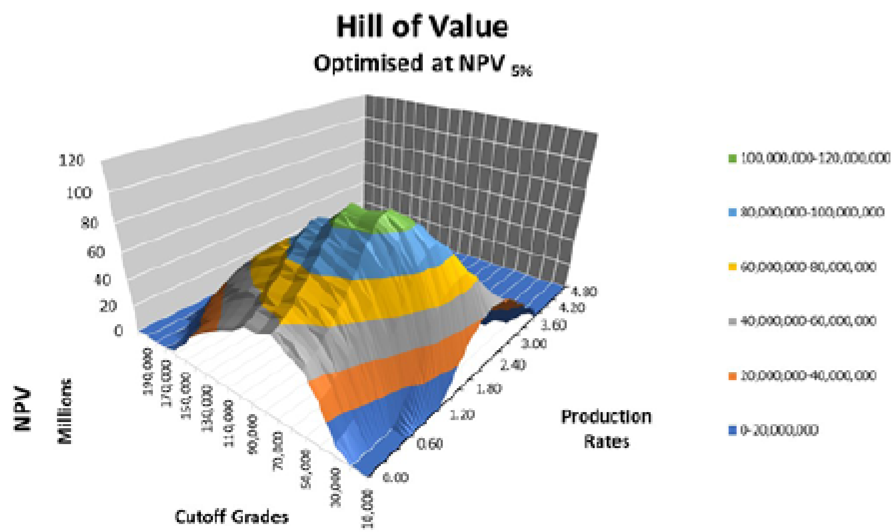


Figure 82: Hill of Value

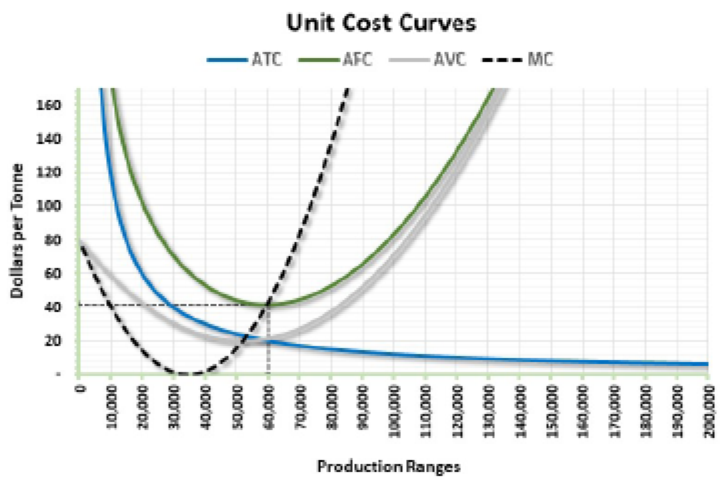


Figure 83: Optimal Cost Structure Solution

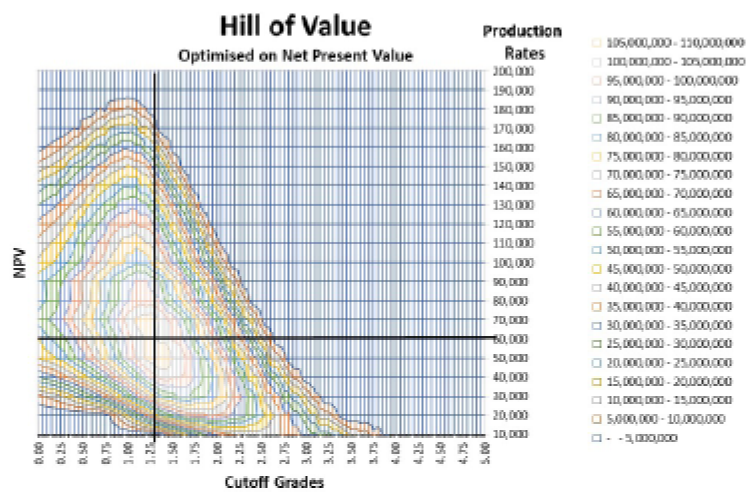


Figure 84: Production Scale and Cut-Off Grades Isolated

● Monte Carlo Analysis

The final economic analysis to consider is the statistical strength of the expected optimal outcome. To do so, the Monte Carlo analysis is run to understand the probability that the determined NPV maximum equates to the expected NPV maximum given when multiple variable outcomes exist.

The Monte Carlo Figure 85 below is the result of 10 000 simulations and indicates the spread of 10 000 probable outcomes given the underlying spread around the variables that determine the NPV of the project.

The deterministic value in this instance was calculated at $ 72 million and the Monte Carlo result is expected to be $ 75 million with a range between $ 45 million and $ 100 million.

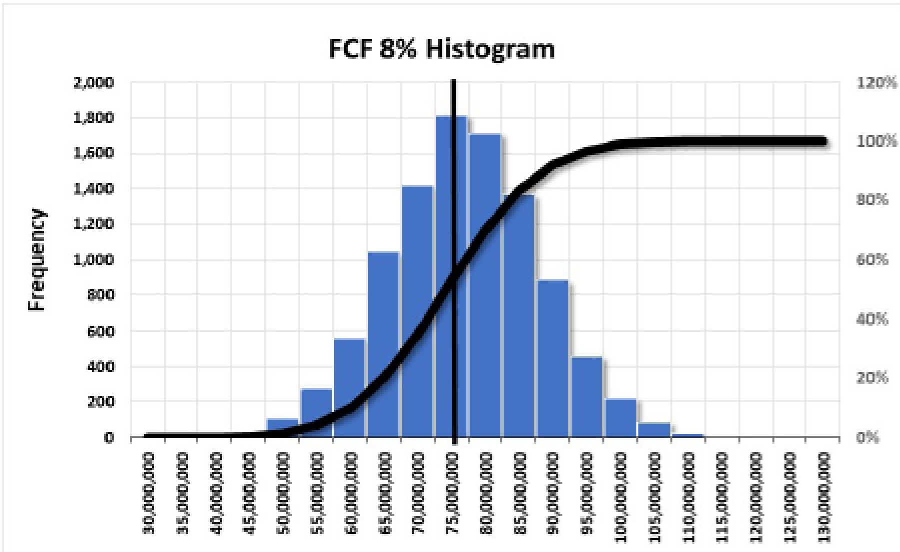


Figure 85: Monte Carlo Analysis

Appendix 1: Valuation Metrics

Present Value

Present Value (PV) is the comparable value today of the relative purchasing power of future money expressed in today's terms. It represents the buying power of future periodic streams of money by discounting money by the rate of inflation. Future cash flow is termed nominal value and discounted cash flow is termed real value.

The formula for calculating the Present Value or PV is:

$$PV = \sum \frac{CF}{(1+r)^t}$$

Where:

PV = Present value

CF = Future cash flows

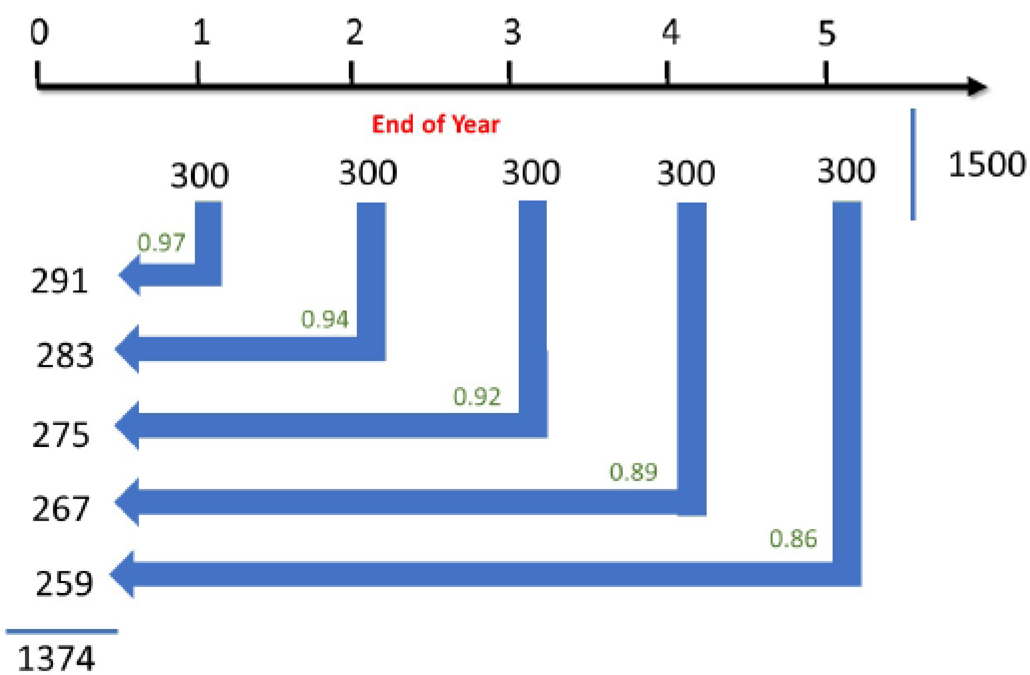
r = Inflation rate

n = Time period

The application of the formula is illustrated as follows:

Present Value Calculation

Period	Cashflow	Discount	Discounted Cashflow
1	300	0.97	291
2	300	0.94	283
3	300	0.92	275
4	300	0.89	267
5	300	0.86	259
Total	1500		1374
	Nominal Value		Real Value



The discounting of periodic cash flows can also be diagrammatically illustrated as shown above. Each periodic cash flow value, i.e. 300, is discounted by the appropriate discount factor. The discount factor is calculated similarly to the PV formula, namely:

$$\text{Discount Factor} = \frac{1}{(1+r)^n}$$

Therefore:

$$\frac{1}{(1+3\%)^2} = 0.94$$

$$\frac{1}{(1+3\%)^2} = 0.94$$

$$\frac{1}{(1+3\%)^3} = 0.92$$

$$\frac{1}{(1+3\%)^4} = 0.89$$

$$\frac{1}{(1+3\%)^5} = 0.86$$

The sum of the nominal future values is 1500, whereas using an inflation rate of 3% per annum yields a real value in today’s terms of 1374.

Net Present Value

Net Present Value (NPV) follows the calculation of Present Value but net of the initial costs against the future cash streams. For example, if the above example was for Mini-mine and the start-up requires 150 units of investment, then the NPV future flows nets of 150 against the PV of future cash flows.

$$\text{NPV} = \mathit{Initial\ Investment} - \sum \frac{CF}{(1+r)^t}$$

Where:

NPV = Net present value

CF = Future cash flows

r = Inflation rate

n = Time period

Present Value Calculation

Period	Cashflow	Discount	Discounted Cashflow
0	-500	1.00	-500
1	300	0.97	291
2	300	0.94	283
3	300	0.92	275
4	300	0.89	267
5	300	0.86	259
Total	1000		874
	Nominal Value		Real Value

Therefore:

Real Net value is – 1 375 less 500 = 874

Internal Rate of Return

The internal rate of return (IRR) is a measure used quantify profitability. IRR is the discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis and represents the annual return that makes the NPV equal to zero.

$$\text{IRR} = \mathit{Initial\ Investment} - \sum \frac{CF}{(1+r)^t} = 0$$

Where:

NPV = Net present value

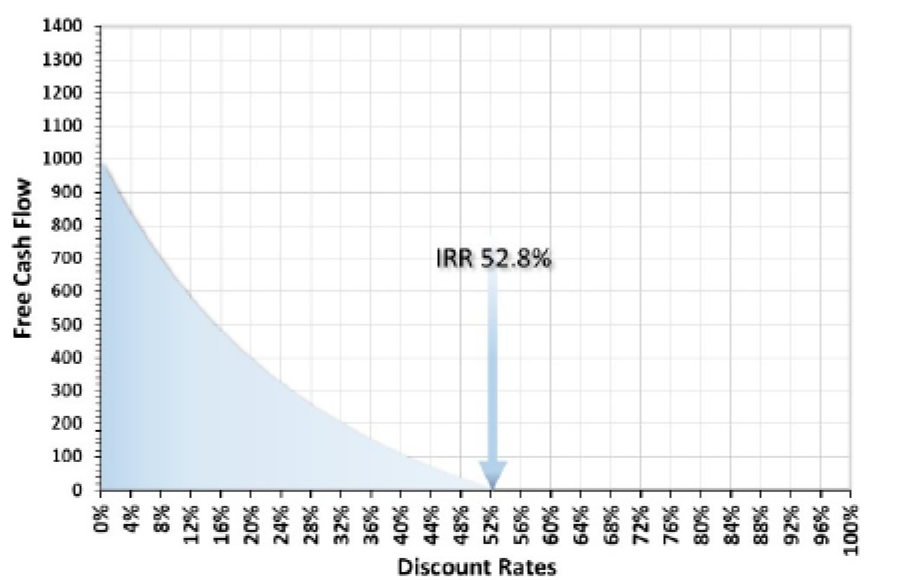
CF = Future cash flows

r = Inflation rate

n = Time period

Zero Present Value Calculation

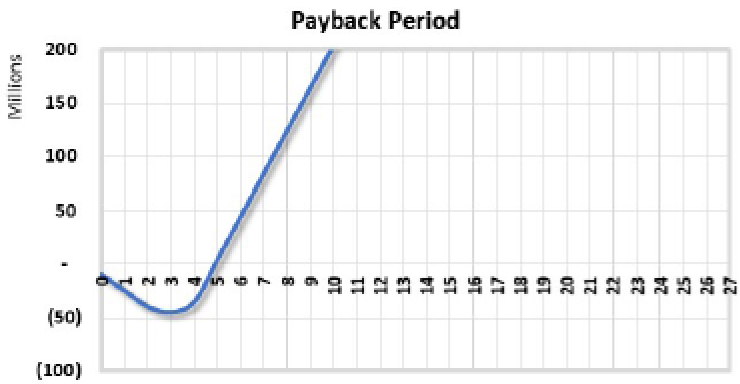
Period	Cashflow	Discount	Discounted Cashflow
0	-500	1.00	-500
1	300	0.65	196
2	300	0.43	128
3	300	0.28	84
4	300	0.18	55
5	300	0.12	36
Total	1000		0
	Nominal Value		Real Value



Discounting the cash streams by 53% results in a 0 NPV which represents the IRR of the future cash streams.

Payback Period

The payback period is the time it takes to recoup the investment made. It is the period at which the sum of negative cash flow equals the sum of the positive cash flows and is best illustrated.



Based on the illustration above the cumulative cash flow becomes positive after 4 years and 7 months. Thus, the project has generated sufficient cash at that time to repay the full investment and therefore the investor does not have any further investment risk.

Life of Mine

The Life of Mine or LoM is the duration in time that the operation will generate cash. The LoM typically includes the construction period plus the depletion period.

The deletion period is calculated by dividing the total Mining Inventory by the annual processing rate. For example, if the Total Mining Inventory contains 30 million tonnes of ore and the processing rate is 144 kilo tonne per annum, then 30 million divided by 144kt is equal to 20.83 years.

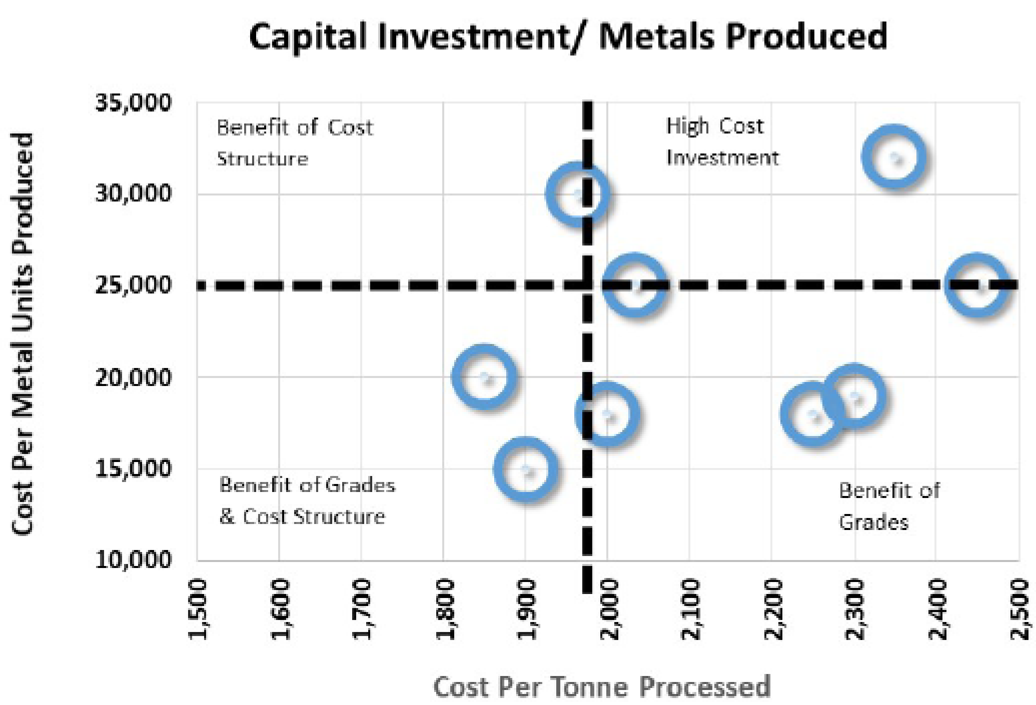
Cost Benefit Ratio

The CBR is the ratio of the sum of positive cash flows divided by the sum of negative cash flows. The interpretation of this is the dollar benefit earned for every dollar invested and is useful when comparing different projects' investment efficiency.

Capital Intensity

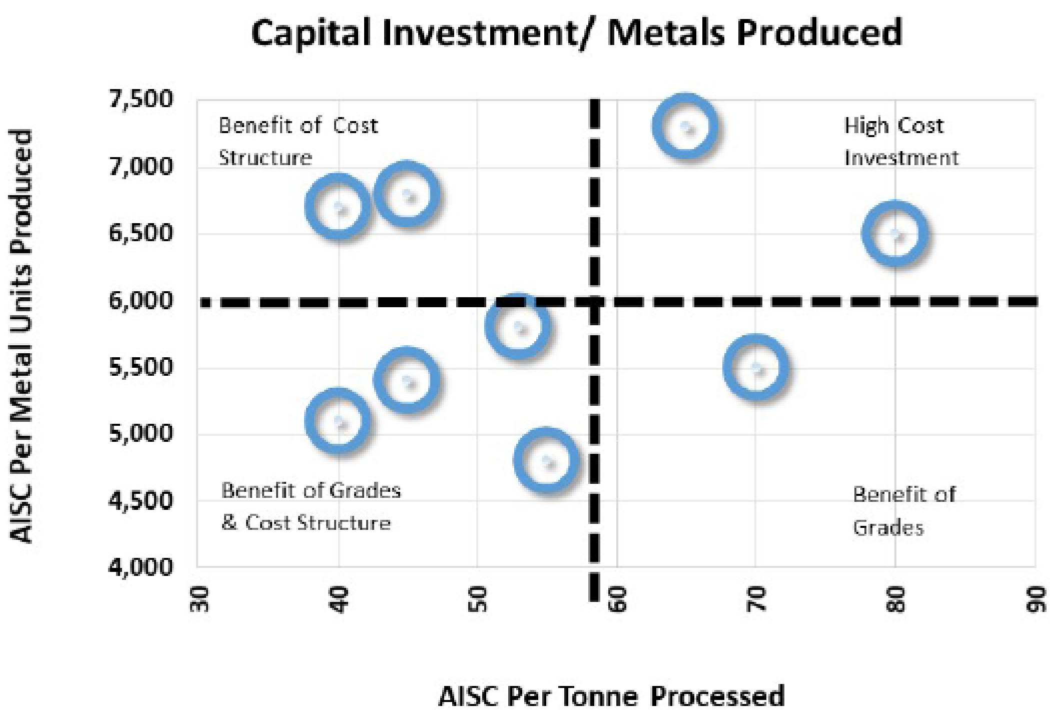
The capital intensity is the calculated unit cost 1 tonne of processing capacity. Thus, if the processing capacity or the production name plate is set at 144ktpa and the investment cost to build the mine is $ 300 million, then the Capital Intensity is $ 300 million divided by 144 thousand, yielding $ 2 083, i.e. the cost of construction per tonne of ore processed.

More often this metric is calculated based on tonnes of metal or metal equivalent. The author is not in favour of using the metal produced or the equivalent metal produced as the grade and volume of by-product metals lowers the metric relative to other projects. For example, two projects could have the same Capital Intensity as measured by ore tonnes processed by different Capital Intensities based on metal produced. The higher grade mine may then be tempted to spend more capital in the misguided belief they have a lower capital intensity. Great for marketing, not great for maximizing NPV.



Operating Unit Costs by Tonne Processed and Metal Recovered

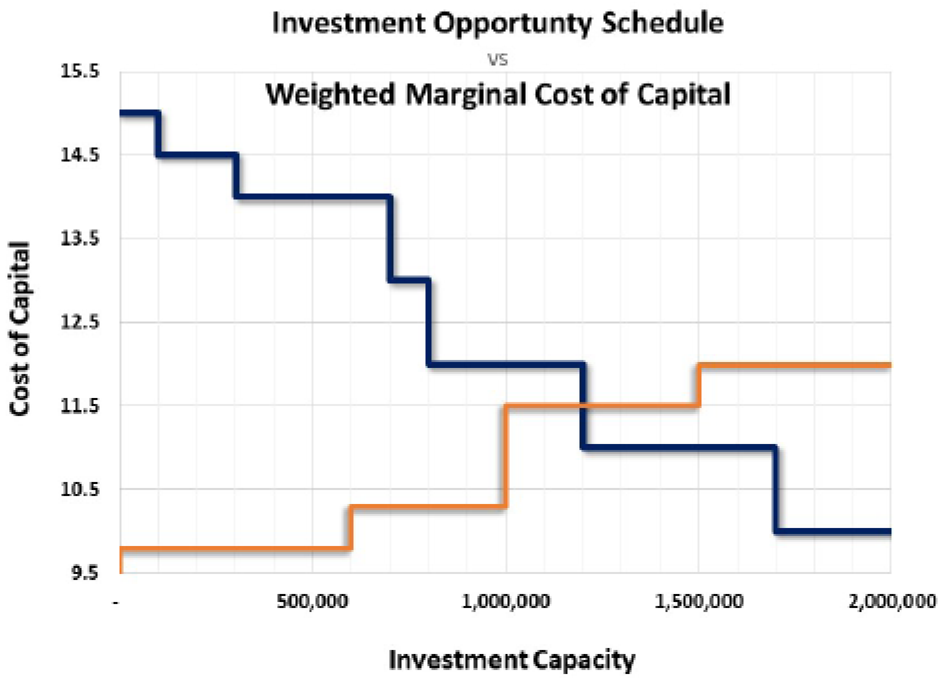
The objective of the all-in sustaining costs (AISC) and all-in costs (AIC) metrics is to provide key stakeholders (i.e. management, shareholders, governments, local communities, etc.) with comparable metrics that reflect as close as possible the full cost of producing and selling an ounce of gold, and which are fully and transparently reconcilable back to amounts reported under Generally Accepted Accounting Principles (GAAP) as published by the Financial Accounting Standards Board (FASB), also referred to as US GAAP or the International Accounting Standards Board (IASB), also referred to as IFRS. AISC and AIC are non-GAAP metrics subject to regulatory and disclosure requirements of the various jurisdictions applicable to the reporting company.



Capital Investment Theory and Capital Rationing

The concept that all projects that have positive NPVs or have IRRs greater than the cost of capital should be accepted, must be considered in the context of available capital. Mining companies operate under capital constraints, i.e. there is a limit to the amount of capital that is available for investing in mining assets. The objective of capital rationing is therefore to select the group of projects that provides the highest overall net present value not requiring more than the capital constraints that a mining company operates under.

As a prerequisite to capital rationing, the best of any mutually exclusive projects must be chosen and grouped together. An approach is to profile the Investment Opportunity Schedule from the group of investment targets against the Weighted Marginal Cost of Capital (WMCC) shown below.As long as the IRR is greater than the WMCC of new financing, the firm should consider the project. All projects that yield less than the firm's WMCC should be filtered out of the project pipeline.



The rationale above describes diminishing returns for new projects and the rising cost of capital for greater amounts of capital for project investment. Projects that fall below the WMCC should be rejected.

The Capital Asset Pricing Model and Weighted Average Cost of Capital

The Capital Asset Pricing Model (CAPM) is widely used in finance and economics to determine the required minimum return that an investor requires to compensate for risk. The alternative to investing in any mine is to either invest in risk-free assets such as government bonds, or deposits in a bank earning interest. Alternative for higher return the investor can buy the stock market index such as the S&P or the Dow Jones Industrial Index or others.

The safest bet or what is regarded as a “risk-free” investment is government bonds because they are underwritten by governments and therefore considered unlikely to default. Government bonds are the lowest yielding investment tools in the market, thus investing on the stock exchange has more allure. The market rate is a measure of the overall market return. Historical growth rates are generally used for projecting the average future growth rate. Hence any investor contemplating investing in individual stocks and or a project such as a mine will seek to beat the rates that they can achieve by investing in stocks or by buying bonds.

The CAPM describes the relationship between required returns and market risk. This model is widely used for pricing risky securities and indicating required returns for assets given the risk of those assets’ relative to other stocks on a stock exchange.

The formula for calculating the expected return of an asset by this method is:

$$ER = R_f + b_i(ER_m - R_f)$$

Where:

ER = Expected return

Rf = Risk free rate

b = Beta of the investment

ERm = Expected growth rate of the market

(ERm -Rf) = Market risk premium

● The risk-free rate is typically measured by the prevailing bank interest rate or bond rate.

● The beta is the degree to which a stock price moves relative to the overall market,

● The expected growth rate of the market overall market.

The model assumes that:

1. Securities markets are competitive and efficient (all relevant information is universally available and absorbed),

2. Markets are dominated by rational, risk averse investors who seek to maximize return on investments.

Although these assumptions have been shown not to hold in reality, the CAPM is still widely used because it is simple and allows for easy comparison of investment alternatives.

The expected return is calculated by multiplying the stock's beta by the market risk premium and then adding the risk-free rate.

For example, consider that an investor is contemplating a stock worth $50 per share today that pays a 4% annual dividend. The stock has a beta compared to the market of 1.4, which means it is riskier than a market portfolio of 1. Assume also, that the risk-free rate is 2.5%. If the market's expected growth rate (S&P or similar index) is 6.43% per annum, then the CAPM returns an Expected of Return of 8%.

$$3.0\% + 1.4x\ (10\% - 3.0\%) = 12.80\%$$

If the only investment around is a single asset, the investor is encouraged to increase the required rate of return to capture as much excess capital as possible. If multiple projects exist but with IRR lower than the required rate of return, the investor can borrow money to lower his required rate of return. An investor return on investment can be amplified if debt is also considered. Also allows for the investor to transfer some risk and lower the cost of investment. Since the cost of debt is lower than the required returns that investor expects from the stock exchange, mixing debt with his equity can lower his expected return rate So, the market value minimum of a deposit relative to and for example to a market index can be determined in this fashion. The incentive for the buyer would be to capture the excess economic value, but the buyer would also be assuming the risk and uncertainty related to capturing the excess value, namely changes to metal prices, grade estimates, head grade projections, recovery rate estimates, cost and cost inflation, exchange rates etc.

The market hurdle rate of return can however be lowered with debt. Debt offers financial leverage, being the Total Liabilities plus Shareholders Equity divided by Share Holders Equity. Since debt is cheaper than equity, the Weighted Average Cost Capital reduces.

The WACC formula is as follows:

WACC = (Cost of Equity x Value of equity) plus (Cost of Debt x Value of Debt)

Assuming cost of equity is 12.80%

Assuming cost of Debt is 3%

Equity value is $ 200 million

Debt value is $ 100 million

Then the WACC is:

Equity	12.80%	x	$ 200	=	25.60
Debt	3.00%	x	$ 100	=	3.00
WACC	9.53 %	=	$ 300	÷	28.80

As a result of the lower cost of capital, the Return of Investment increases 1.84x in this example. Ergo, the economic value of a mining deposit can be enhanced by virtue of an optimal capital structure. The optimal capital structure is a function of the cost of debt, i.e. as more debt is incurred, theoretically the cost of debt increases, resulting in an inflexion point.

The value of the ore deposit can be enhanced by the optimal capital structure being deployed as expressed as:

$$V = EBIT \times (1 - T) / K_a$$

Where:

V = Value of the ore deposit

EBIT = Earnings before interest and taxes

T = Tax rate

Ka = Weighted cost of capital

Valuation of a Mining Asset

Three widely accepted valuation approaches are:

• The market-based approach

Based primarily on the notion of substitution. In this Valuation Approach the Mineral Asset being valued is compared with the transaction value of similar Mineral Assets under similar time and circumstance on an open market. An example of this is comparable sales transactions.

• Income-based approach

Based on the idea of cash flow generation. In this Valuation Approach the anticipated benefits of the potential income or cash flow of a Mineral Asset are analyzed. Examples of this approach are discounted cash flow and multiples of earnings.

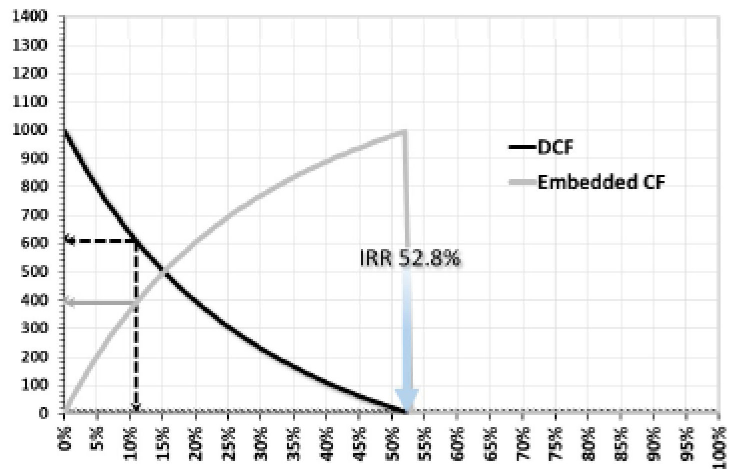
• Cost-based

Based on the idea of cost contribution to Value. In this Valuation Approach the costs incurred on the Mineral Asset are the basis of analysis.

The estimation of a project's value is generally well understood. What is less well understood is the basis for determining the maximum value to pay for a project. The idea is to better understand excess economic value that is generated. Whether the Income-based approach is used or some other method, investment decision making relates to minimum rate of return versus excess economic value potential. The Income-based approach and discounted cash flow are the simplest way to explain the rationale. The calculation of DCF, which is often used interchangeably with NPV, is the computation of excess value about a given discounted rate of return.

A convenient way to explain this by comparing Free Cash Flow (FCF) against Discount rates is to graph the FCF at varying discount rates as illustrated above. Using the WACC and using it as the discount rate helps to illustrate excess value. It has been explained that the IRR is computed where the NPV is zero. Ergo, to achieve an IRR of 52.8% the whole FCF stream must be captured by the investor. If the minimum required rate return (RRR) is 11% $400 will be captured for this return and the remaining FCF is regarded as excess FCF.

Period		Cashflow	Discount	Discounted Cashflow
	0	-500	1.00	-500
	1	300	0.91	273
	2	300	0.83	248
	3	300	0.75	225
	4	300	0.68	205
	5	300	0.62	186
Total		1000		637

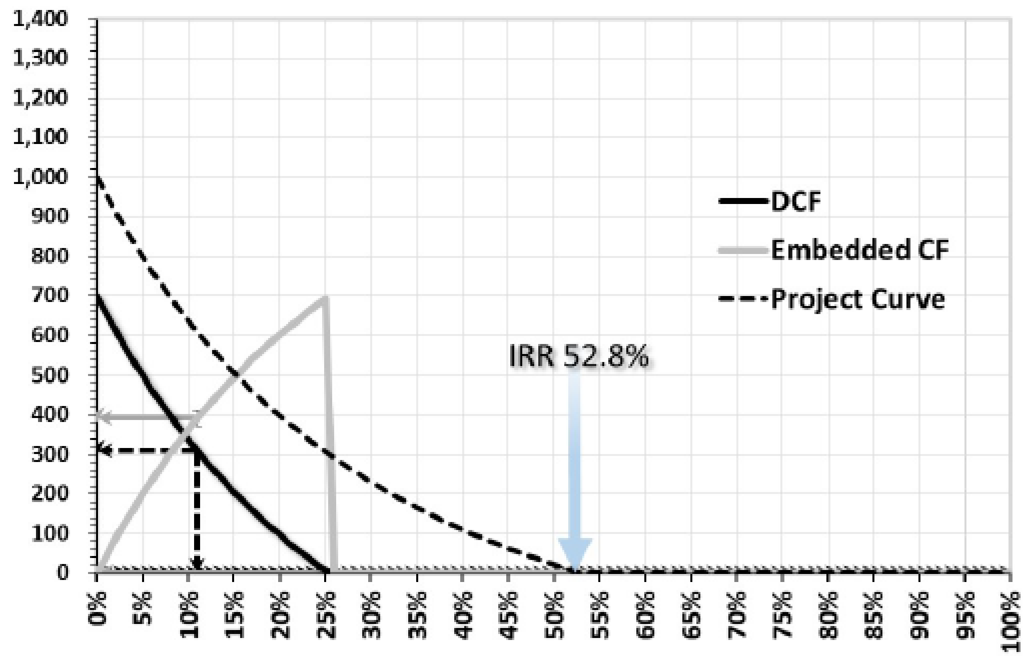


	$	Returns
Free Cash Flow	1,000	52.80%
Minimum RRR	391	11.00%
Excess Value ($NPV_{11\%}$)	**609**	**41.80%**

The above graph and tables seek to explain this. To achieve a 52.28% IRR, $ 1000 of FCF must be appropriated. If the RRR is 11% then $ 391 is appropriated from the FCF while $ 609 of excess value exists. The excess value has a ROR of 41.80%.

These are the project valuation metrics, not to be confused when considering investment. While the project will yield these metrics, buying into the project implies that the returns in the investors hand will be less than the project returns. The reason for this is because the investor will have to invest their contribution into the project plus pay the purchase price.

In this instance the project requires $ 500 invested to yield $ 100 FCF at an IRR of 52.8%. Despite paying for the project, the investor will still need to contribute to the project capital typically in proportion to his equity stake. The project yield will remain constant, assuming that all project assumptions remain constant. The additional payment by the investor reduces the yield in the investor's hand. This can be represented by sliding the curve downwards by the investment made. The formulation is as follows:

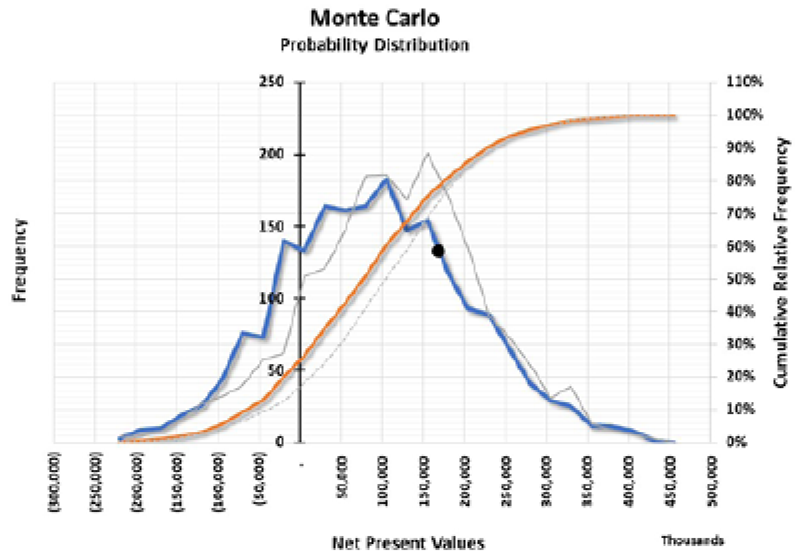


If an investor negotiates a deal that all his investment goes toward the project funding, the investor will realise the project economics of FCF of $ 1000 and IRR of 52.8%. However, if the Investor has to pay a premium over and above the contribution required, then the investment has to be netted off against the FCF, resulting in an IRR lower and net FCF. Assume in this case that in addition to funding the project, $ 300 is required as a premium. The investor's net result for investing and paying the premium is that the IRR reduces to 25% and the net FCF will be $700. The seller realises upfront FCF of $ 300. Importantly, the premium paid upfront is risk free as the seller banks this amount immediately and does not carry any of the risk associated with mining projects described in the body of the book. What is highlighted here, when deal-making a mining project, is that the deal returns can be easily calculated to guide the buyer’s or seller’s position. Both sides wish to maximize return and reduce risk. Investment theory says that the investor can pay a premium up and until the IRR equates to the WACC. The key issue with that is that returns are uncertain, and the investor requires a methodology to test the probability of realising whatever the final outcome of negotiations is.

One last mention is that when negotiating mining projects, no matter at what stage – even exploration status – cash flows can be constructed based on inference and assumption. If cash flows are constructed, it is not dissimilar to scenario planning and quantifying the scenario. The discipline of FCF modelling is that it brings with it a rigorous discipline of accounting for a multivariate number of variables that otherwise may be missed in any valuation.

Appendix 2: Risk and Probability

To consider the strength of the assumptions in a dynamic world, Monet carol simulations can be run on the assumption input variables. It is a useful exercise undertaken to understand the probability of all possible outcomes given ranges around the input assumptions. In truth, the probability distribution will not result in the “True” probability distribution, it will only provide the result of the modeler’s explicit assumptions about the range of variation of the assumption variables. Many of the input assumptions can have a scientifically derived deviation from the mean, such as grade estimates, recovery rates etc., where confidence limits can be defined and used. Others, like price, are simply stabs in the dark as to price volatility and range, but nevertheless it is useful for quantifying how people’s assumptions of the future affect their critical thinking.

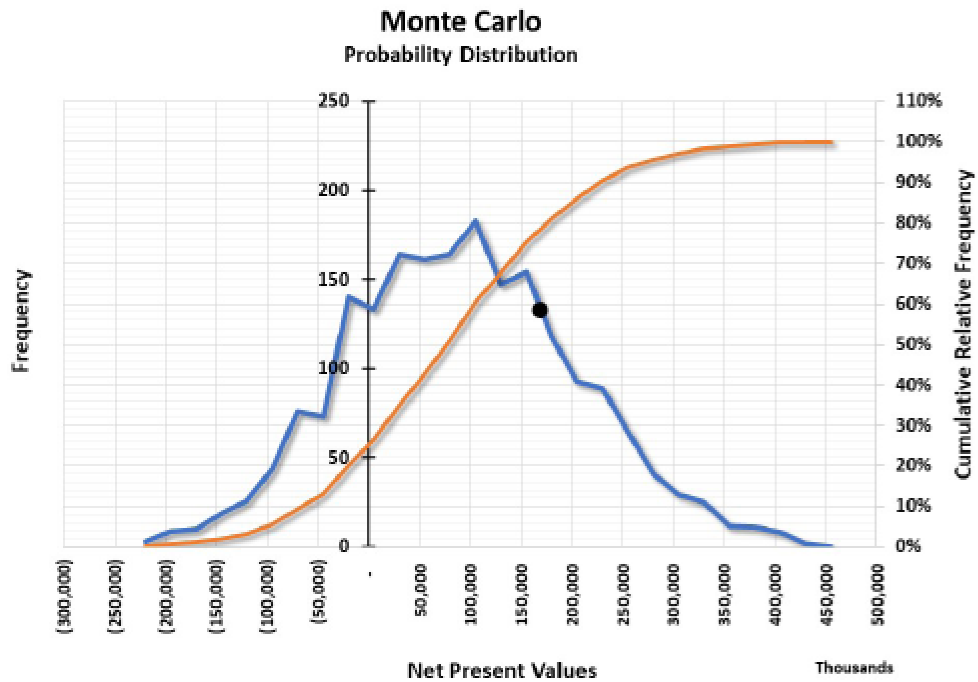


The graph above illustrates the outcome of 2000 iterations based on the basic mining equation. The result of this Monte Carlo for the underlying exercise suggests that the potential for loss is in the order of 25% of possible outcomes and conversely a 75% chance of FCF being above 0. In this exercise it was assumed that $150 million of project financing was required. The maximum loss in this case is $ 200 million and therefore there is the implication that there is less than 2% chance of losing more than what is invested in the project. The underlying point data valuation suggests that the project will yield $ 165 million marked on the probability distribution, whereas the probability plot says that the mode/median and average are lower at approximately $ 100 million. The point data result may well indicate optimism on the assumed variables, and the distribution around these variables has highlighted the degree of optimism. What of the IRR?

Similarly, the ITRR can be plotted. In the above graph the probability distribution of the IRR is shown. Both the IRR and inflation adjusted IRR are considered, useful when using IRR as the means to decide which projects to reject or accept on the Investment Opportunity Schedule. In the underlying example, the IRR is 29% while the probability distribution says the mode, median and average is 18%. When using the NPV/IRR curve this information is useful in order to have the stochastically appropriate starting point for deal making.

Finally, testing high impact variables such as metal prices, for example, and by changing the spread around the assumed price, the impacts on the probability distribution can be ascertained. The next graph shows the impact of changing the standard deviation around the metal price assumed. In this illustration, increasing the standard deviation results in the probability curve shifting to the right, and the implication is that the probability of less than zero return is reduced and the probability that the mode/median and average is closer to the estimated point estimate.

The Monte Carlo probability curve is therefore a good tool to test the veracity of underlying assumptions that affect the basic mining equation and make for better informed decision making and critical thinking, both in deal making and project execution.



		Max	Min	Mean
Start Year	2.00	3.00	2.00	
Basic Mining Equation				
Face Grade	3.00%	3.50%	2.50%	3.00%
Ore Mined	600,000	720,000	480,000	600,000
Ore to Waste Ratio	4.00	6.00	3.00	4.50
Waste %	10%	2%	20%	11.00%
MCF	85%	95%	80%	87.50%
Recovery Rate	90%	95%	85%	90.00%
Metal Price	7,000	10,000	6,000	8,000
Payability	95%	96%	93%	94.50%
TC/RC	65	120	40	80
Penalties	10	15	0	8
Transportation	30	40	30	35
Royalty	3.5%	5%	3%	4.00%
Tax	30%	35%	28%	31.50%
Ore Costs	4.50	6	4.25	5.13
Waste/Development Co:	4.00	5.5	3.8	4.65
Processing Costs	15.00	25	12	18.50
G&A Costs	2.00	2.5	1.8	2.15
Sustaining Capital	4%	8%	2.50%	0.05
Period 0	10%			
Concentrate Grade	30%	30%	25%	27.50%

The basic mining equation being stochastically tested is summarized to the left. The economic factors that are considered to for a assessing a mining projects Free Cash Flows are detailed as are the expected means that are related to the modelers view of the minimum and maximum ranges around each variable.

Each of these variables can have their own probability plot and especially enlightening would be the lot for the metal price so as to test the degree to which conservative metal price assumptions will eventuate on a stochastic basis. B

Appendix 3: Cut-off Grade Optimisation Formulation

Assumptions

Metal Price	6,000
Rate of Production	50
Cost of Production	105
Dilution	10%
Metal Loss	5%

Resources							Basic Mining Equation		Reserves									
Cut-off	Cum Tonnes	Bin Tonnes	Metal	Grade	Ore	Metal	Dilution	Metal Loss	Cum Tonnes	Metal	Grade	Ore	Metal	Revenue	Costs	Profit	LoM	Lom Profit
0.00	1,608	24	45.33	2.82	100%	100%	160.75	2.27	1,768	43.06	2.44	100%	100%	7,306	5,250	2,056	35.37	72,713
0.20	1,584	12	45.33	2.86	99%	100%	158.39	2.27	1,742	43.06	2.47	99%	100%	7,414	5,250	2,164	34.85	75,424
0.40	1,572	16	45.27	2.88	98%	100%	157.15	2.26	1,729	43.01	2.49	98%	100%	7,464	5,250	2,214	34.57	76,559
0.60	1,555	18	45.20	2.91	97%	100%	155.54	2.26	1,711	42.94	2.51	97%	100%	7,529	5,250	2,279	34.22	77,983
0.80	1,538	34	45.11	2.93	96%	100%	153.78	2.26	1,692	42.85	2.53	96%	100%	7,600	5,250	2,350	33.83	79,518
1.00	1,504	72	44.86	2.98	94%	99%	150.39	2.24	1,654	42.62	2.58	94%	99%	7,729	5,250	2,479	33.09	82,012
1.20	1,432	88	44.28	3.09	89%	98%	143.17	2.21	1,575	42.07	2.67	89%	98%	8,013	5,250	2,763	31.50	87,032
1.40	1,344	103	42.90	3.19	84%	95%	134.36	2.15	1,478	40.76	2.76	84%	95%	8,273	5,250	3,023	29.56	89,348
1.60	1,241	102	41.73	3.36	77%	92%	124.07	2.09	1,365	39.65	2.91	77%	92%	8,715	5,250	3,465	27.30	94,585
1.80	1,139	171	40.18	3.53	71%	89%	113.88	2.01	1,253	38.17	3.05	71%	89%	9,140	5,250	3,890	25.05	97,463
2.00	968	75	37.49	3.87	60%	83%	96.76	1.87	1,064	35.61	3.35	60%	83%	10,037	5,250	4,787	21.29	101,903
2.20	892	102	35.01	3.92	56%	77%	89.24	1.75	982	33.26	3.39	56%	77%	10,165	5,250	4,915	19.63	96,494
2.40	790	84	32.05	4.13	49%	72%	79.01	1.63	869	31.02	3.57	49%	72%	10,708	5,250	5,458	17.38	94,870
2.60	706	68	31.04	4.40	44%	68%	70.61	1.55	777	29.49	3.80	44%	68%	11,388	5,250	6,138	15.53	95,354
2.80	638	146	28.67	4.49	40%	63%	63.82	1.43	702	27.24	3.88	40%	63%	11,639	5,250	6,389	14.04	89,709
3.00	492	75	25.66	5.21	31%	57%	49.22	1.28	541	24.38	4.50	31%	57%	13,507	5,250	8,257	10.83	89,416
3.20	418	55	22.35	5.35	26%	49%	41.76	1.12	459	21.23	4.62	26%	49%	13,865	5,250	8,615	9.19	79,143
3.40	363	61	20.12	5.54	23%	44%	36.30	1.01	399	19.12	4.79	23%	44%	14,360	5,250	9,110	7.99	72,764
3.60	302	31	18.46	6.12	19%	41%	30.16	0.92	332	17.54	5.29	19%	41%	15,860	5,250	10,610	6.63	70,396
3.80	270	96	16.81	6.22	17%	37%	27.04	0.84	297	15.97	5.37	17%	37%	16,107	5,250	10,857	5.95	64,592
4.00	175	45	13.79	7.89	11%	30%	17.48	0.69	192	13.10	6.81	11%	30%	20,433	5,250	15,183	3.85	58,395
4.20	150	27	10.94	8.43	8%	24%	12.90	0.55	145	10.40	7.50	8%	24%	21,885	5,250	16,635	2.85	47,413
4.40	103	-	10.60	10.32	6%	23%	10.28	0.53	113	10.07	8.91	6%	23%	26,727	5,250	21,477	2.26	48,550
4.60	103	19	9.42	9.17	6%	21%	10.28	0.47	113	8.95	7.92	6%	21%	23,752	5,250	18,502	2.26	41,826
4.80	84	5	8.53	10.20	5%	19%	8.36	0.43	92	8.10	8.81	5%	19%	26,439	5,250	21,189	1.84	38,957
5.00	79	79	8.53	10.79	5%	19%	7.90	0.43	87	8.10	9.32	5%	19%	27,956	5,250	22,706	1.74	39,481

Variables:

- Reserves — 50 Units
- Revenue per tonne — $/tonne 15
- Fixed Costs — $/tonne 15
- Total Cost Curve Function — $1/3q^{3}-2q^{2}+8q+15$ (where q = the Rate of Production)
- LoM — Reserve base / q

1	2	3	4	5	6	7	8	9	10	11	12	13	14	Discounted LoM Cash Flows					
Mining Rate	Revenue	Fixed Costs	Variable Costs	Total Costs	Profit	Average Fixed	Average Variable	Average Total	Marginal Costs	Life of Mine	LoM Profit/10	NPV	Profit/t	0%	5%	8%	10%	12%	20%
0.00	-	15	0.00	15.00	-15.00	150.00		150.00	15.00										
0.50	7.50	15	3.54	18.54	-11.04	30.00	7.08	37.08	7.08	100.00	-110.42	-110.42	-22.08	(110.42)	(0.84)	(0.05)	(0.01)	(0.00)	(0.00)
1.00	15.00	15	6.33	21.33	-6.33	15.00	6.33	21.33	5.58	50.00	-31.67	-31.67	-6.33	(31.67)	(2.76)	(0.68)	(0.27)	(0.11)	(0.00)
1.50	22.50	15	8.63	23.63	-1.13	10.00	5.75	15.75	4.58	33.33	-3.75	-3.75	-0.75	(3.75)	(0.74)	(0.29)	(0.16)	(0.09)	(0.01)
2.00	30.00	15	10.67	25.67	4.33	7.50	5.33	12.83	4.08	25.00	10.83	10.83	2.17	10.83	3.20	1.58	1.00	0.64	0.11
2.50	37.50	15	12.71	27.71	9.79	6.00	5.08	11.08	4.08	20.00	19.58	19.58	3.92	19.58	7.38	4.20	2.91	2.03	0.51
3.00	45.00	15	15.00	30.00	15.00	5.00	5.00	10.00	4.33	16.67	25.00	25.00	5.00	25.00	11.09	6.93	5.11	3.78	1.20
3.50	52.50	15	17.79	32.79	19.71	4.29	5.08	9.37	5.58	14.29	28.15	28.15	5.63	28.15	14.02	9.38	7.21	5.58	2.08
4.00	60.00	15	21.33	36.33	23.67	3.75	5.33	9.08	7.08	12.50	29.58	29.58	5.92	29.58	16.08	11.30	8.99	7.17	3.03
4.50	67.50	15	25.88	40.88	26.63	3.33	5.75	9.08	9.08	11.11	29.58	29.58	5.92	29.58	17.20	12.58	10.26	8.40	3.90
5.00	75.00	15	31.67	46.67	28.33	3.00	6.33	9.33	11.58	10.00	28.33	28.33	5.67	28.33	17.39	13.12	10.92	9.12	4.58
5.50	82.50	15	38.96	53.96	28.54	2.73	7.08	9.81	14.58	9.09	25.95	25.95	5.19	25.95	16.65	12.89	10.91	9.26	4.95
6.00	90.00	15	48.00	63.00	27.00	2.50	8.00	10.50	18.08	8.33	22.50	22.50	4.50	22.50	14.98	11.85	10.17	8.75	4.92
6.50	97.50	15	59.04	74.04	23.46	2.31	9.08	11.39	22.08	7.69	18.04	18.04	3.61	18.04	12.40	9.98	8.67	7.55	4.44
7.00	105.00	15	72.33	87.33	17.67	2.14	10.33	12.48	26.58	7.14	12.62	12.62	2.52	12.62	8.91	7.28	6.39	5.62	3.43
7.50	112.50	15	88.13	103.13	9.38	2.00	11.75	13.75	31.58	6.67	6.25	6.25	1.25	6.25	4.51	3.74	3.31	2.94	1.85
8.00	120.00	15	106.67	121.67	-1.67	1.88	13.33	15.21	37.08	6.25	-1.04	-1.04	-0.21	(1.04)	(0.77)	(0.64)	(0.57)	(0.51)	(0.33)
8.50	127.50	15	128.21	143.21	-15.71	1.76	15.08	16.85	43.08	5.88	-9.24	-9.24	-1.85	(9.24)	(6.93)	(5.88)	(5.27)	(4.74)	(3.16)
9.00	135.00	15	153.00	168.00	-33.00	1.67	17.00	18.67	49.58	5.56	-18.33	-18.33	-3.67	(18.33)	(13.98)	(11.96)	(10.80)	(9.77)	(6.66)
9.50	142.50	15	181.29	196.29	-53.79	1.58	19.08	20.66	56.58	5.26	-28.31	-28.31	-5.66	(28.31)	(21.90)	(18.88)	(17.14)	(15.59)	(10.84)
10.00	150.00	15	213.33	228.33	-78.33	1.50	21.33	22.83	64.08	5.00	-39.17	-39.17	-7.83	(39.17)	(30.69)	(26.66)	(24.32)	(22.22)	(15.74)

The algorithm which underlies the modelling technique as detailed in this book is set out in the above two tables. Linking the two tables – the ore deposit signatures, and cut-off optimization and the cost curves, defines the basis for determining the Hill of Value. This is the critical link between the optimal economic rate of production and the optimal cut-off grade that maximises NPV.

Appendix 4: Costing Frameworks

COST REPORTING METHODOLOGIES

As McKinsey emphasises, industry cost curves are based on cash costs and represent the economic costs of production, rather than the accounting costs. The mining industry has grappled with economic cost definitions and two competing cost methodologies have emerged, namely the “All-in Sustaining Costs” (AISC) and “All-in Costs” (AIC) metrics, used widely by the gold and precious metals mining industry, and the C(1)(2)(3) cost methodology, used by the base metals industry. The 3C’s methodology has been criticised for inherently under-reporting the cost of production, and for being an accounting, rather than an economic, definition of costs. By definition, the 3C’s considers the following:

- C (1) Net Direct Cash Cost

Represents the cash cost incurred at each processing stage, from mining through to recoverable metal, delivered to market, less net by-product credits (if any).

Direct Cash Costs cover:

● Mining, ore freight and milling costs;

● Ore purchase and freight costs from third parties, in the case of custom smelters or mills;

● Mine site administration and general expenses;

● Concentrate freight, smelting and smelter general and administrative costs;

● Matte freight, refining and refinery general and administrative costs; and

● Marketing costs (freight and selling).

The M1 margin is defined as metal price received, minus C1.

- C (2) Production Cost is the sum of net direct cash costs

The sum of (C1) plus depreciation, depletion, and amortisation.

The M2 margin is defined as metal price received, minus C2.

- C (3) Fully Allocated Cost

The sum of (C2), indirect costs and net interest charges.

Indirect Costs are the cash costs for:

● The portion of corporate and divisional overhead costs attributable to the operation;

● Research and exploration attributable to the operation;

● Royalties and “front-end” taxes (excluding income and profit-related taxes);

● Extraordinary costs, i.e. those incurred because of strikes, unexpected shutdowns, etc.

● Interest charges include all interest paid, both directly attributable to the operation and any corporate allocation (net of any interest received) on short-term loans, long-term loans, corporate bonds, bank overdrafts.

The M3 margin is defined as metal price received, minus C3.

The C(1) cost is often reported by miners in an attempt to convince the market that they have a low cost of production. The C(1) cost in terms of mining economics has a very limited usefulness, and if used indiscriminately, can lead to criticism, such as that of Gavin Thomas (CEO of Kingsgate):

"How can you produce an ounce of gold and not call a government mandated royalty part of your cash costs? Companies are delusional to exclude costs such as royalties from their reported cash costs. I'm a great believer in making the numbers understandable and believable. And if we as an industry don't make those numbers readily understandable to the public, how can we expect them to invest? If sophisticated analysts are confused, how can we expect retail investors not to be confused?"

"The objective of the all-in sustaining costs (AISC) and all-in costs (AIC) metrics is to provide key stakeholders (i.e. management, shareholders, governments, local communities, etc.) with comparable metrics that reflect, as close as possible, the full cost of producing and selling an ounce of gold, and which are fully and transparently reconcilable back to amounts reported under Generally Accepted Accounting Principles (GAAP), as published by the Financial Accounting Standards Board (FASB), also referred to as "US GAAP", or the International Accounting Standards Board (IASB), also referred to as "IFRS". AISC and AIC are non-GAAP metrics, subject to regulatory and disclosure requirements of the various jurisdictions, applicable to the reporting company." (World Gold Council, 2019)

World Gold Council guideline for cost reporting:

- Operating costs

(+) On-site mining costs (on a sales basis);

(+) On-site general and administration;

(+) Royalty/production taxes;

(+) Realised gains or losses on hedges due to operating costs;

(+) Community costs related to current operations;

(+) Permitting costs related to current operations;

(+) Third party transport, smelting and refining costs; and

(+) Operational stripping costs.

- Adjusted operating costs (AOC)

(+) Site-based non-cash remuneration;

(+) Stockpiles and/or inventory write downs; and

(-) By-product credits.

- All-in sustaining costs (AISC)

(+) Corporate general & administration;

(+) Site/based reclamation and remediation – accretion and amortisation;

(+) Sustaining exploration and study costs;

(+) Sustaining capital exploration;

(+) Sustaining capitalised stripping and underground development; and

(+) Sustaining capital expenditure.

- All-in sustaining costs (AISC)

(+) Community costs NOT related to current operations;

(+) Permitting costs NOT related to current operations;

(+) Site based reclamation and remediation NOT related to current operations;

(+) Non-sustaining exploration and study costs;

(+) Non-sustaining capital exploration;

(+) Non-sustaining capitalised stripping and underground development; and

(+) Non-sustaining capital expenditure.

Whilst the AISC methodology has been gaining greater traction among investors, miners and a growing number of analysts and commentators are advocating for additional cost items, as without these, the AISC is not fully costed:

(+) Income tax;

(+) Working capital (except for adjustments to inventory on a sales basis);

(+) All financing charges (including capitalised interest);

(+) Costs related to business combinations, asset acquisitions and asset disposals;

(+) Items needed to normalise earnings, for example impairments on non-current assets and one-time material severance charges.

This book adopts the AISC methodology of costing as it better reflects the economic perspective, rather than the accounting perspective.

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Footnotes

[1] The degree of operating several, is also a function of the base level of sales used, as the point of reference. The closer that the base sales level is to the breakeven point, the greater the operating leverage. Comparison of the degree of operating leverage of two forms is only valid when the base level of sales used for each form in the same.

[2] An important point of reference is that ’linear’ regression is often mistakenly thought to be a linear construct (a straight line). Linear regression refers to an equation that is linear in its coefficients, rather than linear in its variables. Linear regression therefore considers many different ‘non-linear’ functional forms, including exponential, semi-log, polynomial and inverse expressions, while still honouring the linearity rule.

[3] Experience with applying these cost curves to data, is that the S-shaped curve takes precedence over the U-shaped curve, due to curve fitting results and the backwards and forward calculations results. As noted above, the key ingredient in any economic analysis and application of theory, is that a good dose of common sense is required, and the black box approach must be avoided.